BASIC AIR NAVIGATION

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BASIC
AIR NAVIGATION

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FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK AND LONDON
1944

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PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

Modern air transportation owes its success to the efforts of so many groups—scientists, engineers, mechanics, businessmen, meteorologists, and pilots—that it is impossible to isolate the contribution of any one group and say, "This alone made safe flight possible."

I like to think, however, that the success of any enterprise is due in a final sense to the work of the men last entrusted with carrying on the job. If this is true, modern air transportation owes a great debt to the pilot group. Their flying skill and ability to "get there" have contributed largely to the progress of this enterprise.

Modern aids to navigation, while rendering invaluable aid along their routes, have neither simplified their work nor lessened their responsibilities. Indeed, the very existence of these aids has encouraged the development of longer and longer air routes, and pilots are now expected to circle the world as confidently as they once circled the field. To the pilots' already rigorous flight training has been added an equally rigorous training in navigation. This book is written to assist them in the latter field. Basically, navigation is simple, and I have done my best to keep it so.

I wish to express my appreciation and gratitude to the following companies for the use of material credited in this book:

Cox and Stevens Aircraft Corp.
W. and L. E. Gurley.
Kollsman Instrument Division—Square D Company.
Pan American Airways System.
Pioneer Instrument Division—Bendix Aviation Corp.
Transcontinental & Western Air, Inc.
United Air Lines Transport Corporation.

I am also grateful for permission to illustrate the Dalton Mark VII computer and to duplicate in part diagrammatic material previously prepared by me for the Airlines War Training Institute.

ELBERT F. BLACKBURN.

FLUSHING, N.Y.,
January, 1944.

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BASIC AIR NAVIGATION

CHAPTER I

THE BASIC PROBLEM OF THE NAVIGATOR

If the pilot of a plane bound nonstop from New York to Chicago suddenly found his plane passing over Columbus, Ohio, far south of his track, it would be impossible for him to predict accurately his arrival time at Chicago without first determining the direction and velocity of the force that put him off the desired track.

In other words, it is not enough for the navigator to find out from time to time *where* he is; it is the duty of the navigator to find out *why* he got there and to use this knowledge in rerouting his plane toward his destination. If the compasses are good and the steering is well done, the force that puts the plane off the desired track (or ahead or behind schedule) is the wind. *The final objective of the navigator is to reach his destination. His immediate objective is to supply the pilot with compass headings to get there. His ever-present flight problem is to determine the wind and his plane's position for this purpose.*

Too much emphasis cannot be placed on the need for a clear understanding of this basic problem of the navigator in flight; it is quite simple, but in its very simplicity lies the danger that it may be overlooked. Only too often at the end of his training the student navigator finds himself unable to correlate and apply his acquired knowledge.

There are four satisfactory methods of determining the wind in flight; the navigator should select the method most suitable for the given flight conditions. If, for example, a certain method requires a clear view of the earth or sea below the plane, it cannot be used in flying over the top of cloud banks; nor when the plane is cruising beneath the overcast can the navigator use a method that calls first for fixing the plane's position by stars. For each condition of flight there is a *best* method, and it is the duty of the navigator to employ it.

True Directions.—When facing the **true north pole,** *i.e.*, the north end of the axis about which the earth rotates, **true south** is at one's back, **true east** on one's right, and **true west** on one's left. This is illustrated in Fig. 1. In addition, all the possible true directions in which an aircraft may be headed are shown.

Until the study of compasses is taken up in detail, only true directions will be discussed. We shall speak of the **heading** of the plane, the **wind direction** (direction from which the wind comes), and the **track** (either

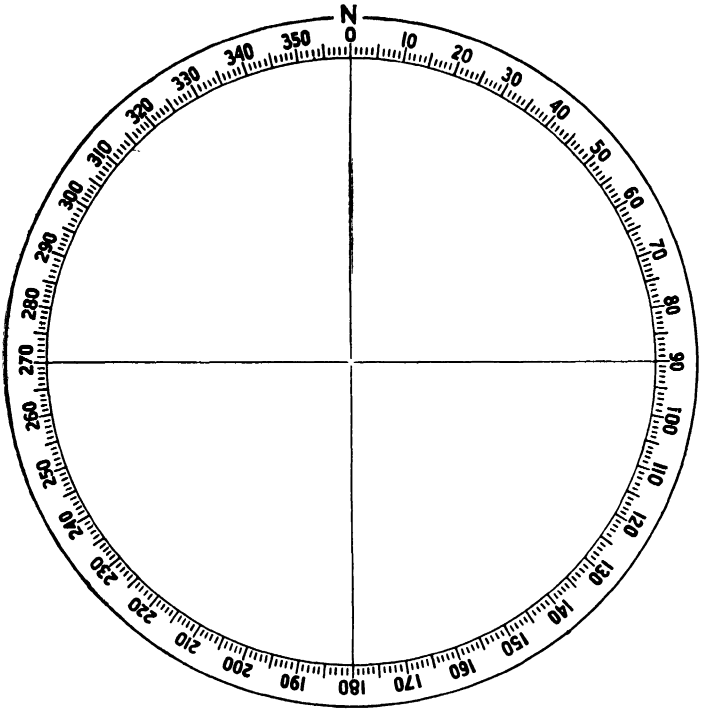


FIG. 1.—True directions.

the desired or the actual path of the plane). All these will be discussed as true directions in conformance with commercial ocean-air terminology.

NOTE: In some air-navigation groups, the *desired track* is designated "true course."

Consider the diagram in Fig. 2. A plane leaves airport A and heads east (90°) toward airport B. If the plane maintains a true air speed of

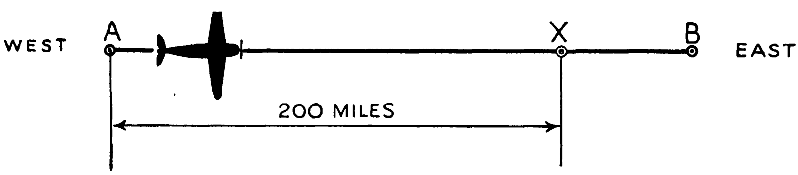


FIG. 2.—The no-wind point.

200 m.p.h. (*i.e.*, actually passes through the air at that speed), it will arrive at point X—in the diagram—exactly 200 miles east of A at the end of 1 hr., provided, of course, that no wind acts to force it sideways,

speed it up, or retard it. Such a point, the point at which the plane would arrive if it traveled through still air, is called the **no-wind point.**

Effect of Wind.—Naturally, if the plane flies in a mass of air that is itself moving over the face of the earth, the plane may not arrive at the no-wind point, for it will partake of the movement of the air in addition to the forward motion obtained from its engines. The value of the no-wind point as an aid in the determination of the plane's position under this condition is almost self-evident. The no-wind position for some given period of time—usually an hour—can be spotted on the chart; from that point the wind force and velocity known to have acted on the plane can be applied, and in this manner the position of the plane at the end of the hour becomes known.

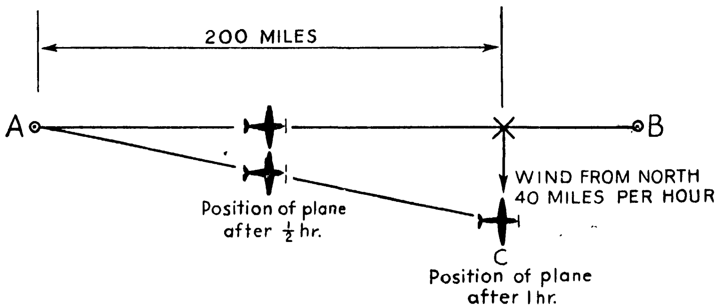


FIG. 3.—The effect of wind on a plane in flight.

Study the diagram in Fig. 3. If the air mass through which the plane is flying remains stationary the plane will arrive at the no-wind point X. If the air mass moves southward at the rate of 40 m.p.h. (*i.e.*, if a north 40 m.p.h. wind acts on the plane), the plane will arrive at a point 40 miles south of X at the end of 1 hr. Its heading will not have changed, its air speed will be the same, but it definitely will not have proceeded straight toward its destination B. In point of fact, half an hour after having left A the plane was 20 miles south of the desired track joining A and B. Reference to the illustration will show that the plane proceeded over the earth along the path AC, a track that differed from the heading of the aircraft by several degrees. This difference between the true heading of the plane and the track it follows is called the **drift.** In this case the plane drifted to the right, but had the wind blown from the other side left drift would have occurred.

Refer again to the diagram. Understand clearly that the pilot alone was responsible for the true direction in which the nose of the aircraft was headed; that he may have known nothing at all about the wind acting on his plane, especially if flying through clouds; and that, while he kept the plane on a true heading of 90°, it actually moved along a track, or path, several degrees right of the intended track AB.

Summary.—If a plane maintains a true air speed of 200 m.p.h., it makes those 200 m.p.h. through the air in the direction in which the nose of the plane is headed. If no wind acts on the plane, the track made good over the ground is exactly the same as the heading. Under this condition the speed of the aircraft over the ground is equal, mile for mile, to its speed through the air. If, however, a wind blows from one side or the other, the plane will not make a track over the face of the earth in the direction in which it is headed; it will make a track somewhat to one side of its heading. It follows logically that the plane's speed over the ground (**ground speed**) must always be measured along its track over the ground and the plane's true air speed must always be measured along the true direction in which the plane is headed and proceeding through the air.

Parts of the Triangle of Velocities.—What we have just discussed and illustrated is the so-called "triangle of velocities." One side of this

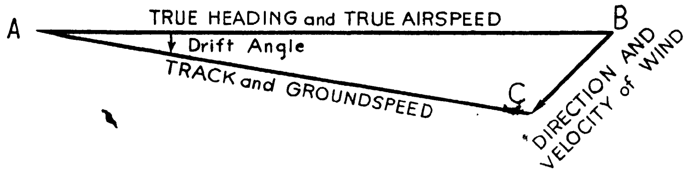


FIG. 4.—Parts of the triangle of velocities.

triangle is always drawn in the direction of the true heading; and, using any convenient scale, its length is made equal to the true air speed. The second side is drawn in the direction of the plane's track; and, using the same scale, it is made equal to the ground speed in length. The length of the third side of this triangle, obtained by drawing a line from the end of the true-heading side to the end of the track side, indicates the velocity of the wind according to the same scale. The direction of the third side shows the true direction of the wind (see Fig. 4).

A little study of the triangle will show the student that, when certain parts of the triangle have been determined in the air, other parts of the triangle can be found automatically. A suitable combination of known parts may be placed on the navigator's chart and the missing parts drawn in. *In large measure the ability of a navigator is his ability to obtain a combination of parts suitable for a solution of this triangle.*

On any flight the navigator may determine the true heading and true air speed of his plane by reading the compass and air-speed indicator and applying certain known corrections to those readings. This true heading may then be drawn on the chart from the last known position of the plane. The number of miles the plane has traveled through the air since leaving that position should then be measured along this line. If the present

location of the plane is known, a line should be drawn from the last known position to the plane's present position. Thus two sides of the triangle become known, and the angle of drift between them as well. The navigator may now close the triangle by drawing an arrow from the end of the true heading and air-speed line to the end of the track and ground-speed line. This third side represents, in direction, the direction of the wind that has forced the plane *off* to one side. In length it represents the strength of that force. If the other two sides of the triangle are drawn in for exactly 1 hr. duration of flight, the length of the wind side shows 1 hr. average wind. If the sides, on the other hand, are drawn in for 1½ hr. duration of flight, the length of the wind side shows 1½ times the average hourly velocity of the wind.

It will perhaps be difficult for the student navigator to visualize all the practical solutions of the triangle of velocities in the air, *i.e.*, all the methods by which, when certain parts of the triangle become known, the remaining parts may be found. None of the parts of the triangle are ever given to the navigator, although, as stated before, the true heading and air speed may readily be found by applying certain known corrections to the face readings of the compass and air-speed indicator. Because of the ease with which they may be found, these two factors together with two others are frequently employed in solutions that result in the determination of wind direction and velocity.

There are four and only four practical solutions of this triangle, including the one just given, that may be used in the air to find out what is happening to the plane. Having found out what is happening to the plane, one of two other combinations of parts is used to route the plane toward its destination.

Test

A. From the following numbered list of the various parts of the triangle of velocities, select the six *practical* combinations of four factors each that, when known to the navigator, enable him to solve (close) the triangle.

NOTE: In working this problem the student is to draw no triangles but is to try to visualize the various solutions. He should bear in mind that *any* four factors, if known, will not allow an unambiguous solution of the triangle. The *manner* in which these factors are actually obtained will be taken up at the proper time.

1. True heading.
2. True air speed.
3. Plane's track.
4. Plane's ground speed.
5. Wind direction.
6. Wind velocity.
7. Drift angle.

B. Now draw the triangles. Do they close?

C. Check your answers with the solutions that follow; these are the only combinations you will ever use.

Finding out what is happening to the aircraft

Solution 1

Prerequisite: 1. True heading.
2. True air speed.
3. Track made good.
4. Ground speed.

The use of this solution is limited to flight conditions suitable for the determination of the plane's track and ground speed, and from the solution so made the navigator learns the average direction and velocity of the wind that for some past period has been acting on the plane. Such flight conditions would normally obtain in flying over known and visible landmarks, in flying on instruments over known radio stations, or in flying over the ocean under conditions that enable the navigator to determine the position of the plane by celestial observations. In any of these cases, the position of the plane becomes known from time to time, and the track and ground speed made good become available for use in this type of solution.

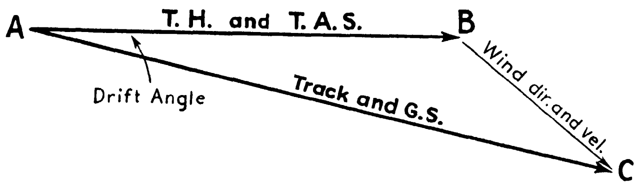


FIG. 5.—Solution 1 of the triangle of velocities.

Solution 2

Prerequisite: 1. True heading.
2. True air speed.
5. Wind direction.
6. Wind velocity.

The employment of this solution presupposes a knowledge of the wind acting on the plane, and from the solution the navigator acquires a knowledge of the track and ground speed being made by the plane. It is perfectly possible to determine the wind even at sea without knowledge of the plane's position, provided only that the surface is visible. The true heading and true air speed may be obtained from the compass and air-speed indicator, with due allowance for errors in their readings, and the wind direction and velocity should be obtained by solving the so-called "double-drift" or "wind-star problem."

If solution 2 is employed frequently, there is no reason why accurate knowledge of the plane's position may not be carried forward for hours. The author has flown 6½ hr. over the open sea using this solution alone, with a resulting error in position of only 12 miles. The disadvantage of this solution lies in the fact that, in order to determine the wind direction and velocity by means of the wind-star problem, the plane must be headed off track for a period of 3 to 10 min.

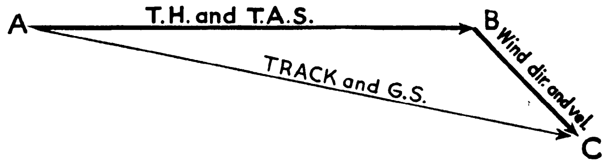


FIG. 6.—Solution 2 of the triangle of velocities.

Later, this method of determining the wind will be discussed in greater detail. For the moment remember that it may be used day or night over open water and during the daytime over land provided only that the surface of the earth be clearly visible.

Solution 3

Prerequisite: 1. True heading.
2. True air speed.
5. Wind direction.
7. Drift angle.

The use of this solution will enable the navigator while in flight to determine the track, ground speed, and wind velocity. It is, however,

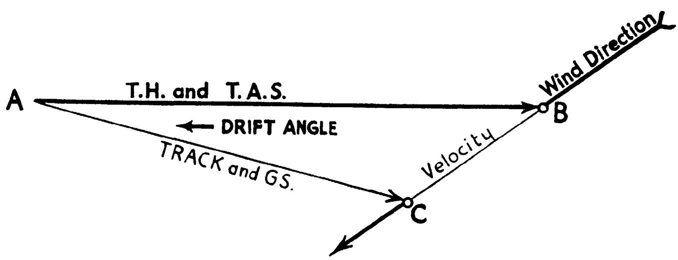


FIG. 7.—Solution 3 of the triangle of velocities.

limited to daytime low-altitude contact flight conditions. In general, when flying at 2,000 ft. or less over the open sea, the navigator will not be much in error if he assumes the wind direction at his altitude to be the same as that shown by the ripples or whitecaps on the surface. This is not always true, as radical wind shifts are occasionally experienced at low altitudes, but exceptions to this general rule are rare. The drift

of the plane may sometimes be estimated, but drift indicators if available should always be used.

The point should be made at once that it is unwise to estimate the velocity of the wind. Experienced navigators are able to tell the difference between a surface wind of 10 m.p.h. and one of 15 m.p.h. by noting the effect of the wind on the water. Nevertheless, no navigator can tell with certainty the difference between a 40 m.p.h. wind and a 50 m.p.h. wind by studying the size of the whitecaps. Even were it possible to estimate closely the surface wind velocity, it would be unwise to expect the wind at 2,000 ft. to have the same velocity, for it is well known that velocity quite often increases with altitude.

Over land this solution may possibly be used under daytime contact flight conditions, provided that the pilot can descend safely to within 1,000 or 2,000 ft. of the terrain and note the smoke direction, tree motion, or other evidence of surface wind direction. Primarily, however, this method of closing the triangle of velocities resolves itself into a low-altitude over-the-ocean proposition, and under these conditions its value cannot be overestimated.

Solution 4

Prerequisite: 1. True heading.
2. True air speed.
4. Ground speed.
7. Drift angle.

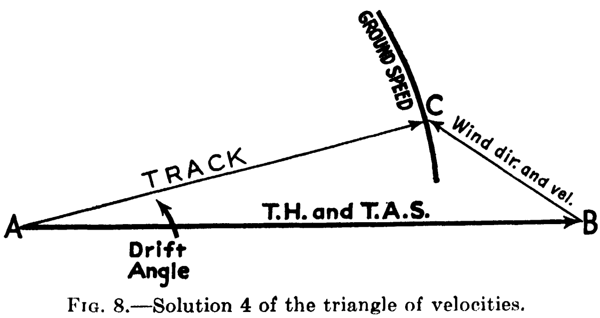


FIG. 8.—Solution 4 of the triangle of velocities.

Unlike the previous solution, this one may be used at almost any altitude provided that the surface of the earth or sea is visible. Again the true heading of the plane and the true air speed are to be obtained from the compass and air-speed indicators, with due allowance for their errors; the last two factors, ground speed and drift, may both be found from a special drift indicator. In using this instrument, ground speed is determined by timing the passage of some fixed object, such as a barn or a prominent tree or a whitecap on the sea, as it passes successive lines

etched on the drift indicator. For the information of some students who may not be familiar with whitecap movement, whitecaps formed in deep water do not travel with the wave motion. After breaking, the swell rolls on underneath the foam and leaves them behind.

Practical difficulties are sometimes experienced at low altitudes owing to the speed with which such objects enter and pass through the drift indicator's field of vision, and sometimes in flying above 10,000 ft. it is difficult to keep track of small whitecaps on the surface. Then, too, though the timing of the object's movement across the face of the drift indicator is usually done with a stop watch and a long series of these observations is averaged, the ground speed so ascertained is not likely to be accurate within less than 5 m.p.h. The question arises whether or not this solution should be used at all when, under the same flight conditions, solution 2 may be used. This may be answered by stating that the use of solution 2, involving the use of the wind-star problem, requires the plane to be headed away from its destination for 3 to 10 min.; solution 4 does not. Rather, under good clear conditions, this solution will enable the navigator to determine at frequent intervals *without heading away from his destination* the plane's track, ground speed, wind direction, and wind velocity all within fairly close limits.

Solutions used in routing or rerouting the plane

Solution 5

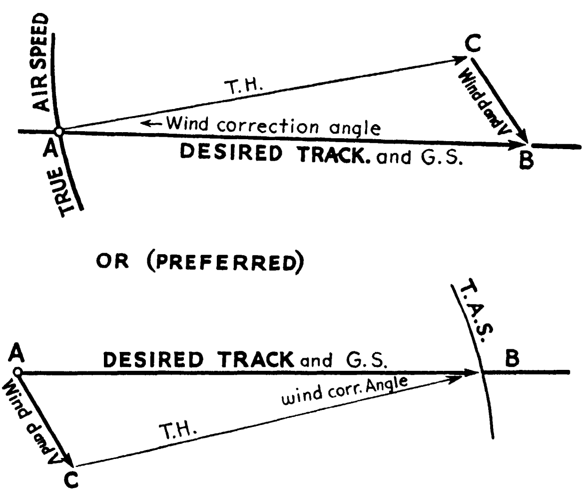


FIG. 9.—Solution 5 of the triangle of velocities.

Prerequisite: 2. True air speed.
3. Track desired.
5. Wind direction.
6. Wind velocity.

This solution is used by the navigator to determine the ground speed of the aircraft along some desired track. It also supplies the required true heading for the flight; of course, this in turn indicates how much the plane will drift when making good its track. This *predetermined* drift angle is sometimes termed the *wind-allowance angle, wind-correction angle,* or *correction angle.*

Normally, Solution 5 is made over and over again on the ground prior to the take-off, in order that flight times for various possible altitudes and wind conditions may be studied and analyzed. Once the flight is under way it is used after every determination of the wind direction and velocity in order that both the required true heading and the anticipated ground speed may be ascertained. In practice, if the navigator finds his plane off the originally intended track, he must lay down a new track on his chart. Tables or graphs showing the best cruising air speed should be at hand for his guidance, and the wind direction and velocity should be known as a result of having employed one of the four solutions of the triangle previously mentioned. With these data the triangle is closed, and new headings are supplied the pilots.

Solution 6

Prerequisite: 3. Track—desired to follow.
4. Ground speed—desired to make.
5. Wind direction.
6. Wind velocity.

This solution is used when the plane is required to make a definite ground speed, possibly to make connections with another service or

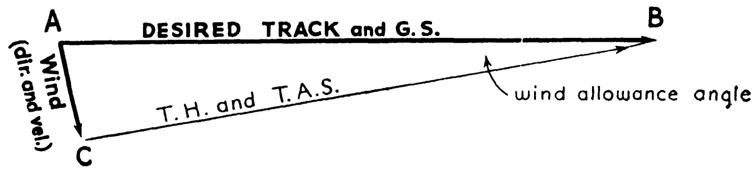


FIG. 10.—Solution 6 of the triangle of velocities.

to reach an airport before dark or before bad weather sets in. Solution of the triangle with these factors gives the navigator the true air speed to be maintained and the true heading needed to counteract the effect of the wind. There are very definite limitations to its use. In domestic air-line operation it is customary to vary the air speed in order to maintain schedule, and if the air speed resulting from this solution falls within the safe operating air speeds of the plane it may well be used. In the case of long-range ocean operations it is customary to maintain air speeds that are most efficient from a fuel-consumption standpoint, and only on short hops will the ocean navigator find occasion to use this

solution. Obviously, in either case, with strong tail winds, air speeds so low as to be undesirable from a mechanical standpoint might be indicated —and, of course, rejected.

Impractical Solutions of the Triangle.—Other solutions of the triangle are possible but of questionable value. The triangle *may*, for example, be closed if the following four factors are obtained:

3. Plane's track made good.
5. Wind direction.
6. Wind velocity.
7. Drift angle.

It is conceivable that these factors might become known to the navigator in flight, and from them he might determine his present true heading and air speed. He should not, however, go out of his way to find these factors by closing a triangle of velocities when he can obtain them with less effort from his instrument panel.

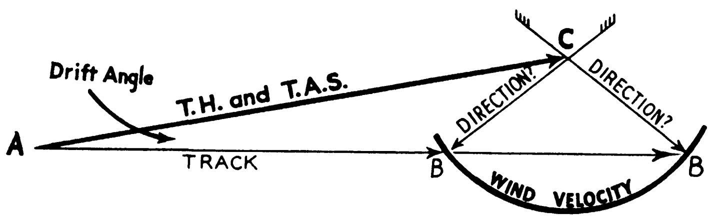


FIG. 11.—Defective closure of the triangle of velocities.

Likewise the triangle may be closed by using the following four factors:

1. True heading.
2. True air speed.
6. Wind velocity.
7. Drift angle.

At first inspection, this looks like a good approach to the problem when wind direction and ground speed must be ascertained. Closer study, however, will show the student that the use of factor 6 (wind velocity) allows of two possible solutions from which two different ground speeds and two different wind directions might result (see Fig. 11). It should be unnecessary to stress the point that there is no place in air navigation for ambiguous solutions of this type.

It is also possible to close the triangle if the following four factors become known:

1. True heading.
2. True air speed.
4. Ground speed.
6. Wind velocity.

This solution is equally ambiguous; it may result in two different tracks and two different wind directions (see Fig. 12).

We have discussed so far the basic problem of the navigator. Under given flight conditions certain factors are more easily ascertained than others. When these have been determined, a solution of the triangle of velocities becomes possible, and other factors of equal importance concerning the flight become known to the navigator. From this discussion, the student should have gathered that much of the navigator's informa-

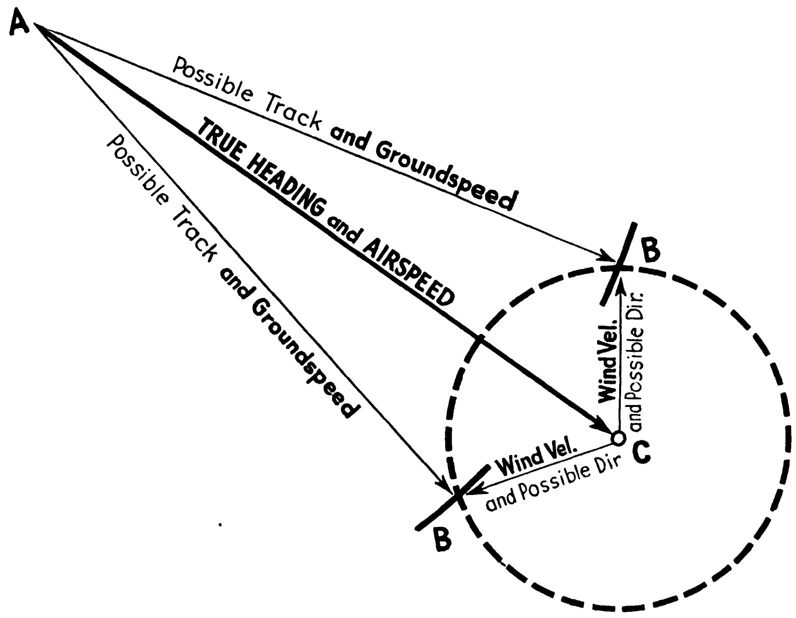


FIG. 12.—Defective closure of the triangle of velocities.

tion must be obtained from or through the use of instruments. The following are those most frequently used; there are many types of each:

Air-speed indicators.

Altimeters.

Compasses.

Drift indicators.

Temperature gauges.

The important thing for the student to bear in mind as he takes up the study of these instruments in a later chapter is that their face readings may not be true. The north end of the compass needle may point far to the east or west of true north, the air-speed indicator may read more or less than the true air speed of the plane, and the altimeter may not indicate true altitude.

CHAPTER II

PREFLIGHT DUTY OF THE DOMESTIC AIR-LINE NAVIGATOR

Navigation in domestic air-line operation is performed by the pilots and copilots since the size of the crew does not permit the employment of a separate crew member for this duty. Long familiarity with their routes makes them experts in this field. Much of their navigation consists in flying along radio beams; radio range stations and radio marker beacons make possible frequent and accurate checks on the plane's progress; and, under contact flight conditions, visual observation plays an important part in their orientation. Later we shall discuss celestial navigation and its possible application to domestic air-line operation; but as long as radio aids to navigation continue to be available, it is difficult to see how a higher record of safe flying could be achieved.

Safety Factor—Minimum Fuel Requirements.—Government regulation and company policy stipulate minimum fuel reserves for scheduled air-line operation. According to government regulation a plane when operating under contact flight conditions must carry sufficient extra fuel to remain in the air 45 min. after having reached its destination. When part of a flight is to be flown under instrument cónditions, sufficient gas must be carried to enable the plane to proceed to its destination and thence to its alternate airport and then to circle 45 min. before landing. Government requirements in this respect are considered *minimum* safe flight requirements; for the most part, individual air lines require their planes to be loaded with much more than this amount of fuel. Before studying the domestic air-line navigation problem the student should become familiar with some of the principles underlying domestic air-line operation. To this end the following brief discussion is offered.

Domestic Air-line Operation.—Analysis of air-line operation schedules shows that rather conservative ground speeds are used in determining their published intercity flight times. This is a matter of sound business since it makes for more "on time" arrivals than would be possible if higher ground speeds were used as a basis for these schedules. In other words, pilots normally have a little extra horsepower and air speed available to use in meeting schedule if head winds are encountered. Transcontinental and Western Air, for example, bases its west-bound schedules on air speeds resulting from the development of 550 hp. per engine, and allowance is made for a 15 m.p.h. head wind. These sched-

ules, furthermore, take into account the time necessary to assume normal or average flight altitude and to meet schedule with this allowance. More specifically, horsepower may be increased to an allowable maximum of 625 per engine to overcome stronger head winds, avoid severe storm areas, or make up time lost from other causes. Rather than develop more than 625 hp. per engine, the planes are allowed to drop behind schedule.

The United Air Lines operation schedule is based on its past operating experience. Its pilots, knowing the speed required to meet schedule, calculate the horsepower necessary to make that speed. Of course, in some cases the scheduled flight time cannot be made because excessive

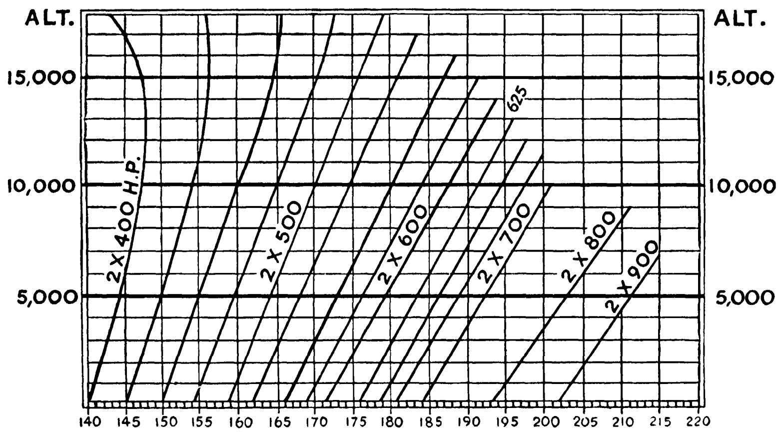


FIG. 13.—DC-3 true air speeds for various combinations of altitude and horsepower.

wind velocities would demand the development of horsepower beyond the maximum limits set for engine operation.

Thus the problem of the air line is to maintain schedule, and the pilot's problem is to deal with the vagaries of wind and weather in an effort to do this. Route mileage and scheduled flight time establish the ground speed to be made between check points; the pilot with his knowledge of tracks and weather conditions determines air speeds sufficient to overcome the winds and meet schedule. These speeds can be determined before the flight commences; but since winds and weather may change en route, some modification of these predetermined air speeds may become necessary.

Preflight Work of the Navigator.—The simplest procedure is to draw up a flight plan based on air speeds resulting from the development of normal cruising horsepower (in the case of a DC-3 perhaps 500 or 550 per engine); then as the flight progresses, the horsepower and air speeds may be increased to allowable limits in order to make up lost time. A

flight plan drawn up along these lines calls for Solution 5 of the triangle of velocities. Reference to the discussion in Chap. I (page 9) shows that the following factors must be known before the solution may be undertaken:

2. True air speed.
3. Track desired.
5. Wind direction.
6. Wind velocity.

In one form or another this information is made available to the pilot at the air base; graphs are usually furnished showing true air speeds, charts are supplied showing tracks and distances, and data on winds and weather are ordinarily available in forecast form. A typical air-speed graph from which a pilot might obtain air speeds is shown in Fig. 13.

Use of Graph in Determining Air Speeds.—Note that at 5,000 ft., in developing 550 hp. per engine, an air speed of about 173 m.p.h. is obtained. If the pilot desires to stay at this altitude and cruise at 183 m.p.h. the horsepower developed per engine must be increased to 625.

PROBLEMS

1. What horsepower must be developed at 4,000 ft. to produce a true air speed (TAS) of 175 m.p.h.? *Ans.:* 575.
2. What horsepower must be developed at 10,000 ft. to produce a true air speed of 180 m.p.h.? *Ans.:* 550.

If company regulation calls for normal development of 550 hp. per engine, it should be comparatively easy for the pilot to obtain air speeds from this graph for any flight altitude. Air speeds 10 or 12 m.p.h. greater may be achieved if 625 hp. instead of 550 hp. per engine is developed.

Tracks and Distances from Air-line Route Charts.—Most major air lines furnish their pilots with small charts of their regular routes, showing not only the tracks and distances between check points but minimum safe flight altitudes as well. A chart is shown in Fig. 14 giving these bare essentials; much more detail, however, is desirable and is normally included. Notice especially that westbound flights must be made at *even* 1,000-ft. altitudes and eastbound flights at *odd* 1,000-ft. levels. If these small charts are not made available, the pilot must obtain the information for himself from more general charts or maps of the route. U.S. Coast and Geodetic Survey aeronautical charts (strip maps) are generally used for this purpose.

Route Winds and Weather.—Winds at flight altitudes should be forecast for the pilot by the local meteorologist, or the latest weather maps should be at hand for his guidance. While air-line pilots receive considerable training in weather-map analysis and can forecast winds

and weather conditions for themselves with reasonable accuracy, company or government specialists in this field are consulted whenever possible. Their forecasts are based not so much on the analysis of any single weather map as on continuous observation of shifting weather conditions. A typical weather forecast for the Columbus to Chicago route is shown in Fig. 15.

The Time Element in a Forecast.—The forecast in Fig. 15 shows the winds at 2,000-, 4,000-, and 6,000-ft. altitudes between Columbus and Indianapolis, Indianapolis and Lafayette, and Lafayette and Chicago.

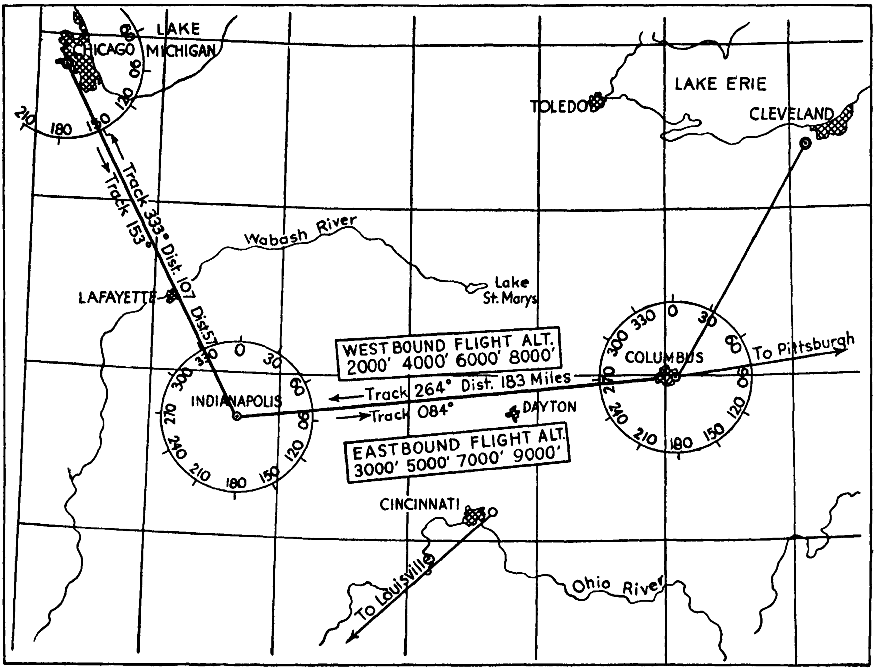


FIG. 14.—Simplified route chart.

In studying these winds the student must bear in mind that he is studying a forecast—not a weather report. Winds and weather shown in a forecast are predicted for the time the plane is expected to pass through the forecast area. The departure time of the plane has been entered at the top of the forecast sheet; unless the plane takes off at that time or close to it, the pilot may not encounter the forecast winds. Those between Lafayette and Chicago, for example, have been predicted by the meteorologist for the time the plane is expected to pass through that area. Similarly, the terminal forecast sets forth wind and weather conditions likely to be encountered at these points if the trip is made on schedule. The same applies to Remarks. To repeat, this is not a

weather report but a forecast and is intended to apply to a particular scheduled flight. This latter fact may serve to explain why air lines have maintained their own meteorology departments even though forecasts are issued from time to time by the government.

MID-WEST AIR, INC.

FLIGHT-FORECAST # 3000
TRIP # 100 ROUTE Co-Cg via Id. DATE 4-1-43 TIME 0600 CST

ZONE	DISTANCE	WIND DIRECTION AND VELOCITY 2,000 Ft.	4,000 Ft.	6,000 Ft.
Co - Id	183	250°-26 mph	250°-45 mph	270°-50 mph
Id - Lf	57	270 - 30	250 - 45	270 - 50
Lf - Cg	107	315 - 32	290 - 25	290 - 30

TERMINAL FORECAST

TERM	TIME CST	WEATHER	LOWER CLOUDS AMT—TYPE—BASE—TOPS	HIGH CLOUDS AMT—TYPE—BASE—TOPS	VIS	SFC DIR.	WIND VEL.	REMARKS
Co		LOW SCATTERED	4 Cu 1500-4000	NONE	6 mi	225°	16 m/h	VISIBILITY
Id		LOW BROKEN	6 Cb 1200-5000	NONE	8 mi.	250°	20	REDUCED
Cg		MOD. RAIN	8 Cb 1500-16000	NONE	3 mi.	315°	25	BY RAIN

REMARKS

Cold front moving southeast-ward approximately 20 mph will be accompanied by modt. thunder showers and will lie across route at La Fayette. Base of clouds near front 600 feet, tops 18,000, moderate chops and drafts. Freezing level 9,000 feet.

FIG. 15.—A weather forecast. The following abbreviations have been used:

Co—Columbus
Id—Indianapolis
Lf—Lafayette
Cg—Chicago
cu—cumulus clouds
cb—cumulo
SFC—surface wind
vis—visibility

Analyzing Flight Times.—Desired tracks, cruising air speeds, and forecast winds enter into the analysis of possible flight times; and, for this purpose, the winds predicted in the forecast for each zone and altitude have been transferred to the flight-analysis sheet shown in Fig. 16. Zone distances and tracks shown in the analysis were obtained from the chart in Fig. 14. True air speeds shown in the column TAS were obtained from the graph in Fig. 13. In this manner, all the factors required for Solution 5 of the triangle of velocities (page 9) become readily available; the ground speed likely to be made good and the probable flight time through each zone can now be determined graphically.

At 2,000 ft. (between Columbus and Indianapolis) the anticipated ground speed is shown to be 143 m.p.h., the true heading 262°, and the

PLANE 250,000 **MID-WEST AIR, Inc.** DATE 4-1-43

FLIGHT NO. 100 **FLIGHT ANALYSIS** DEPT. 0600 C.S.T.

BASED ON FORECAST 3000

2,000 feet

ZONE DIST.	TRACK	WIND	T.A.S.	G.S.	T.H.	TIME	SCHED. TIME
CO-ID 183	264	250-26	168	143	262	77 min.	70
ID-LF 57	333	270-30	168	153	323	22.5 "	22
LF-CG 107	333	315-32	168				40
347	TOTALS						132

4,000 feet

ZONE DIST.	TRACK	WIND	T.A.S.	G.S.	T.H.	TIME	SCHED. TIME
183	264	250-45	171				70
57	333	250-45	171				22
107	333	290-25	171				40
	TOTALS						132

6,000 feet

ZONE DIST.	TRACK	WIND	T.A.S.	G.S.	T.H.	TIME	SCHED. TIME
183	264	270-50	174				70
57	333	270-50	174				22
107	333	290-30	174				40
	TOTALS						132

Fig. 16.—Flight analysis.

anticipated flight time 77 min. This latter may be compared with the scheduled flight time of 70 min.

Solving for True Heading, Ground Speed, and Zone Times.

PROBLEMS

1. Determine the ground speed, true heading, and anticipated flight time between Indianapolis and Lafayette.

Procedure: Draw the desired track AB; select a convenient point A, and at A draw the wind arrow from the direction in which the wind is blowing (270°). The length of the wind arrow is made equal to 30 units since the velocity is 30 m.p.h. Using a pair of dividers or a pencil compass, open to a spread of 168 units (the air speed), and swing an arc from the end of the wind arrow C until it crosses the track line AB. This point of crossing establishes one corner of the triangle of velocities. Complete the triangle by drawing in the missing side—the true-heading side. Reference to Fig. 17 shows that the direction of the true-heading side is 323°; *i.e.*, a 10° allowance must be made for the wind. The length of the ground-speed side of the triangle scales 153 units. These data are entered in the appropriate columns of the flight-time analysis sheet.

2. Following the procedure outlined above, complete the flight-time analysis shown in Fig. 16 for all zones and altitudes.

NOTE: Flight time in minutes for each zone is obtained by means of the following equation:

$$\text{Time} = \frac{60 \times \text{zone distance}}{\text{ground speed}}$$

Choosing the Flight Altitude.—From the foregoing analysis it becomes evident that the best speed between Columbus and Indianapolis can be made at 2,000 ft.; between Indianapolis and Lafayette at 4,000 ft.; and between Lafayette and Chicago at 4,000 and 6,000 ft. Inasmuch as the total flight time at these best altitudes adds up to 9 min. more than the scheduled flight time, the pilot will be expected to develop maximum allowable horsepower to regain those 9 min. Although the flight is of comparatively short duration, the plane will probably arrive in Chicago on schedule. Of course, the choice of flight altitudes is influenced by passenger comfort and general weather conditions; bumpy air, for example, certainly would be avoided if meals were to be served.

NOTE: In this flight little if any time could be saved by climbing.

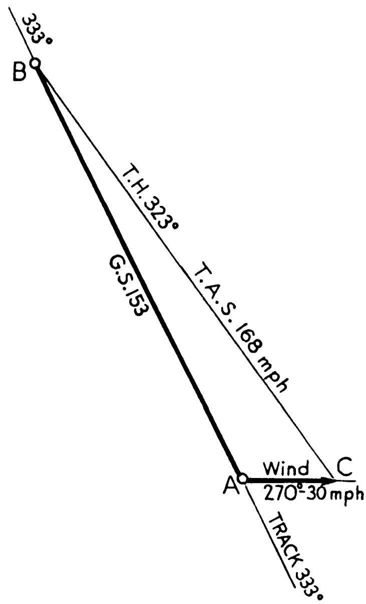


FIG. 17.—Graphic solution for true heading and ground speed.

Obtaining Tracks and Distances from Airways Charts.—The point has been reached now where the student, if he is not to become a theoretical navigator, should begin to lay down his own tracks and scale his own flight distances. For this purpose it is recommended that U.S. Coast and Geodetic Survey Chart 3060*b* be employed. This is an aeronautical planning chart covering the entire United States as well as portions of Canada and Mexico. It embodies, on a small scale, all the regional and sectional airways charts published for this country. A small-scale reproduction is shown in Fig. 18.

On this chart the principal airways are outlined in red, and the navigator's problem is to determine the tracks they follow and the statute mileage along them. A statute mileage scale or, to be more exact, six such scales are printed at the bottom of the sheet. Each

applies to a particular area running left and right (east and west) on the chart; for example, the scale marked 30° applies to a band across the

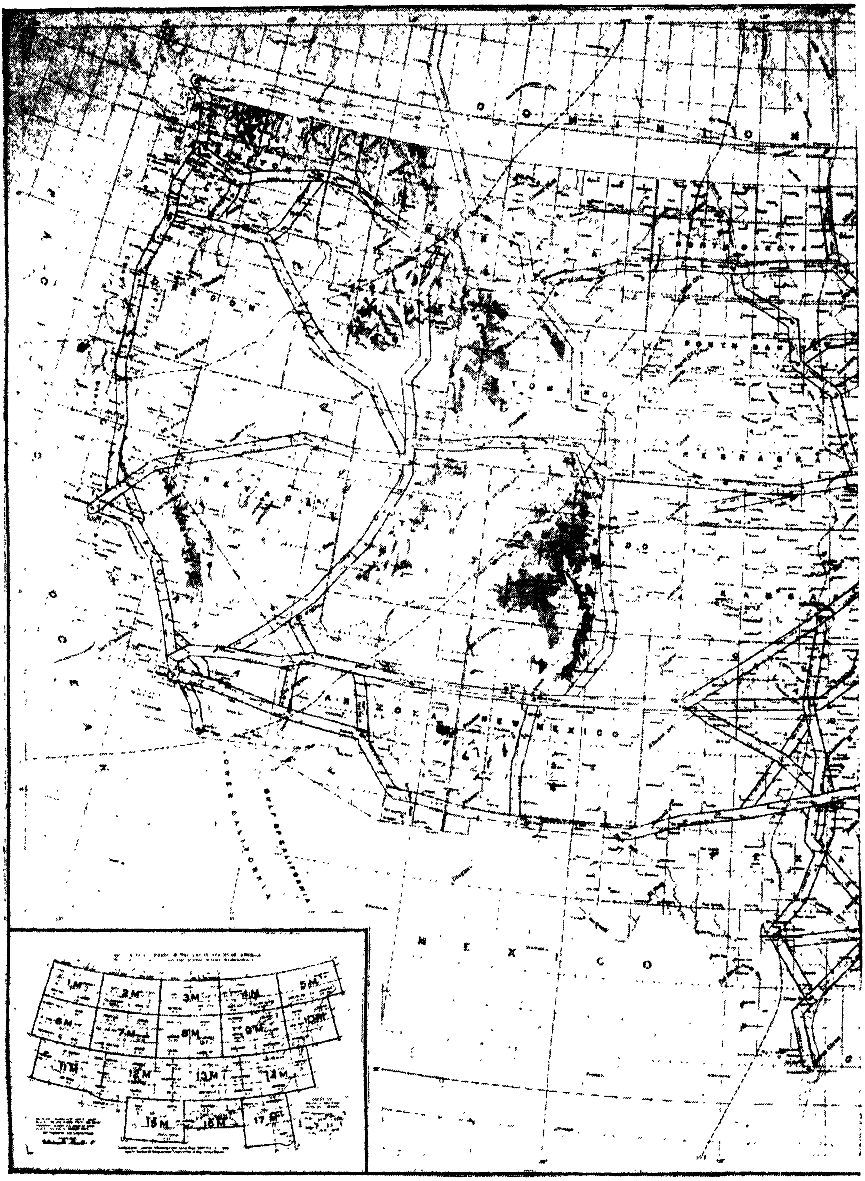
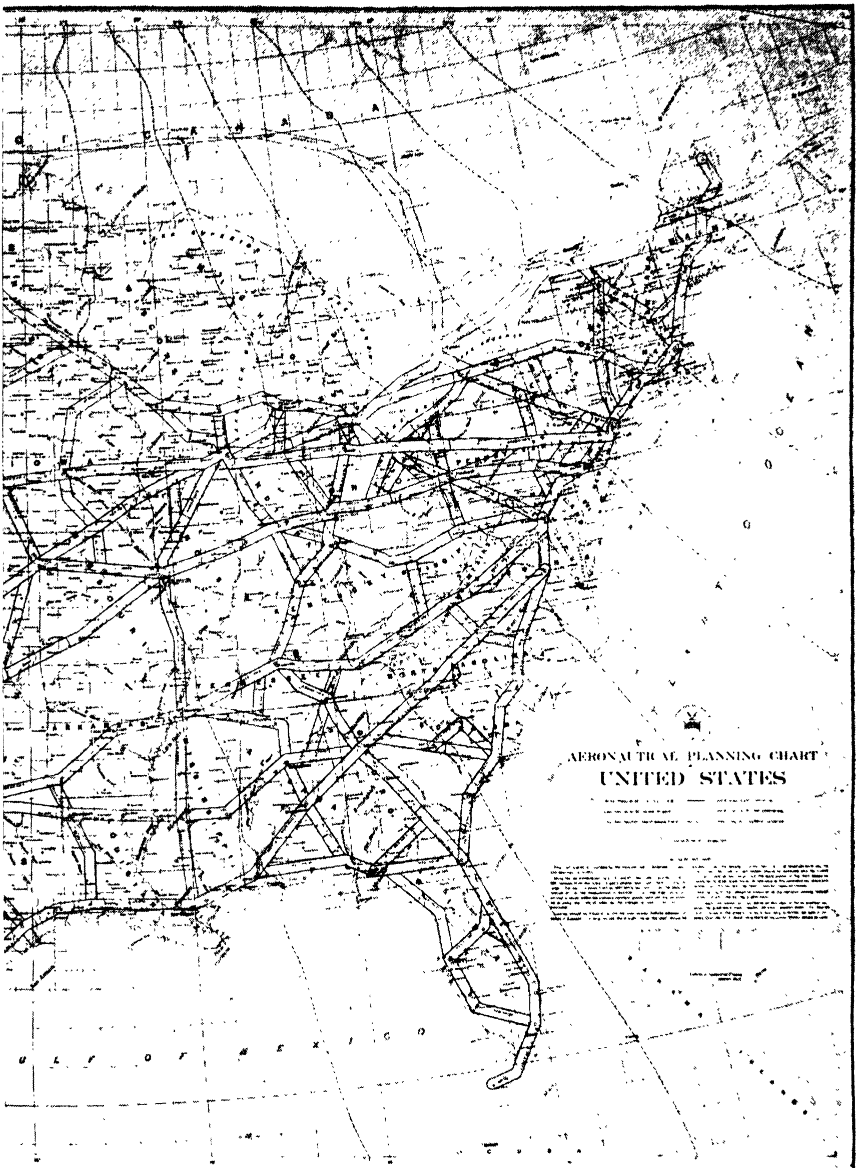


FIG. 18.—U.S. Coast and Geo-

United States containing Jacksonville, Houston, and El Paso. The scale marked 40° should be used in measuring mileages near New York,

Chicago, or Salt Lake City, etc. The direct distance from New York to Chicago when measured on the latter, the correct scale, is about 10



detic Survey Chart 3060*b*.

miles longer than it would seem to be if it were measured on the former scale. The need for employing more than one mileage scale on a chart

is due to the fact that a sphere, such as the earth, cannot be represented on a flat chart without introducing a certain amount of distortion. Distortion, *i.e.*, the enlarged or shrunken representation of certain areas, is to be thought of not as a defect, but rather as a characteristic of all charts—hence the need for different mileage scales for different areas.

A straight-line track drawn on this type of chart does not cross all meridians of longitude (north-south lines) at the same angle, as may be seen in Fig. 19. Such a line has been drawn from San Francisco

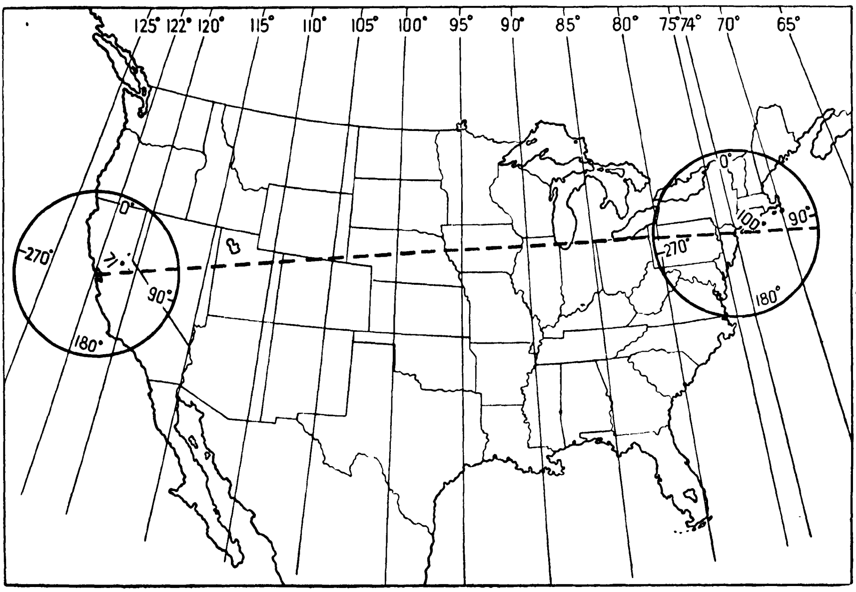


Fig. 19.—San Francisco–New York track on a Lambert conformal conic projection.

to New York; if it is not apparent to the eye that at San Francisco the angle between this track and north is different from the angle between this track and north at New York, a protractor used as indicated will quickly establish the fact.

This track takes the true direction of 71° at San Francisco, and at New York the true direction, always measured clockwise from north, is 100°. Inspection of the chart will show that New York is on the 74th meridian (west of Greenwich, England) and that San Francisco is on the 122nd. If the 29° difference between the initial and final track is divided by the 48° difference in longitude between the two cities, it will be found that each meridian on this chart leans toward or converges on the one next to it by $\frac{6}{10}$°. The line between San Francisco and New

York represents the shortest route between these cities; it is to be thought of, however, not as a *single* track, but rather as a series of short tracks, each of which makes a slightly different angle with the meridian it crosses. If the navigator chooses to consider that there are actually 48 short tracks in the one long one, he may, if there is no wind, shift the true heading of the plane $\frac{6}{10}°$ every time he crosses a meridian. If he chooses to consider the long track as actually being a series of 16 tracks each crossing 3° degrees of longitude, he may alter the true heading of the plane $3 \times \frac{6}{10}°$, or, roughly, 2°, whenever the flight has progressed through 3° of longitude.

The general practice among navigators is to divide the entire track into legs covering approximately 4° of longitude; the track for each leg is measured clockwise from north at the central meridian. Thus an average track is obtained for the leg that, at most, will take the plane but a few miles off the main track laid down. Note should be made that this slight divergence will always be to the *south* of the main track in northern latitudes and *north* of the main track in southern latitudes. Since the whole of the United States is in north latitude, the navigator will doubtless be most concerned with the first of these facts. If it is desired to keep on airways between cities, the navigator has no choice but to obtain the track and distance for each section of the airway—however short—in a manner similar to that just described.

Problem: An amphibian is ordered to proceed from Miami's municipal airport to Corpus Christi, Tex. Draw a straight line between the airports, and divide the desired track into three legs according to the length of the zones for which winds have been forecast, as shown in Fig. 20.

It may seem contradictory to advise the student to break the entire track into three separate legs, some of which will cover more than 4° of longitude, after the statement that this would be about the maximum difference of longitude for any flight leg. For the purpose of analyzing the possible flight times along the route, however, longer legs are sometimes used. The track is taken from the meridian at the center of the leg, as previously explained. In other words, a degree or two of difference in track will not materially alter computed ground speeds in the flight-time analysis.

Using air speeds of 131 m.p.h. at 2,000 ft., 136 m.p.h. at 4,000 ft., and 141 m.p.h. at 8,000 ft., work up the flight-time analysis (Fig. 21) for this trip, and determine the best single flight altitude.

According to the analysis there is very little difference between the flight time at 1,000 and 3,000 ft.; in point of fact, the flight time for the trip at 7,000 ft. is only about 20 min. longer.

The question now arises as to fuel requirements. Inspection of the graph (Fig. 22) indicates that at 2,000 ft. a gas load of 4,600 lb. is neces-

FILED 0730 GMT
PLACE MIA
DATE 4/1/43

MID-WEST AIR, Inc.

WEATHER FORECAST NO. ____

NX 10 MAP 0600 GMT

TRIP 500 TRACK MIA-CR DEPARTURE TIME 0800 GCT

STD. FORM A1-5A

ZONE ENDING	STATE WEATHER	AMT TYP BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	WINDS 2000 FT.	4000 FT.	8000 FT.	12000 FT.
300	CLOUDY	.3 Cu 20	4000′	.6 Ac 14,000′	9000+	350°-10 Kts.	310-15	290-25	
700	PARTLY CLOUDY	.5 Sc 20	3000′	NIL	9000+	040°-8 Kts.	010-10	340-14	
1073	PARTLY CLOUDY	.4 Cu 20	4000′	.2 Ac 12,000′	9000+	120°-6 Kts	150-10	270-10	

TERMINALS	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	SURFACE WIND	VISIBILITY		
MIA	CLOUDY	5 Sc 18	3000′	.8 Ac 14,000′	9000+	NNW 14 Kts.	12 Miles		
CR	PARTLY CLOUDY	2 Fr. Cu 20	3000′	.3 Ac 12,000′	9000+	ESE 10 Kts.	16 Miles		
NO	CLEAR	NIL	—	NIL	9000+	CALM	10 Miles		

REMARKS:
High pressure area centered at New Orleans, mdt. turbc. in level below 4000′. No surface fronts

METEOROLOGIST Black

FIG. 20.—Flight forecast: Miami–Corpus Christi.

sary, at 4,000 ft. a gas load of 4,900 lb. is required, and at 8,000 ft. a gas load of 5,400 lb. must be carried.

Other things being equal the trip would be made at the lowest level since less fuel is required, but inspection of the flight forecast indicates

PLANE *NX 10* **MID-WEST AIR, Inc.** DATE *4-1-43*

FLIGHT NO. *500* **FLIGHT ANALYSIS** DEPT. *0800 GCT*

BASED ON FORECAST

2,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
I 300	280	350-10	131			
II 400	276	040-08	131			
III 373	273	120-06	131			
	TOTALS					4600 LBS.

4,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
I 300	280	310-15	136			
II 400	276	010-10	136			
III 373	273	150-10	136			
	TOTALS					4900 LBS.

8,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
I 300	280	290-25	141			
II 400	276	340-14	141			
III 373	273	270-10	141			
	TOTALS					5400 LBS.

FIG. 21.—Flight analysis: Miami–Corpus Christi.

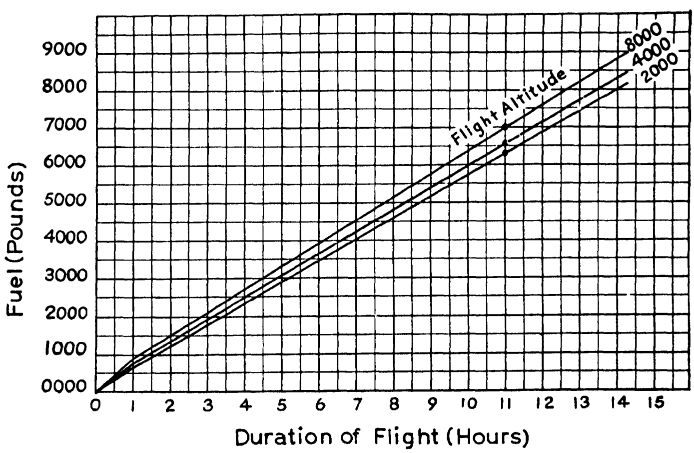


FIG. 22.—Fuel consumption curve NX-10. Maximum gross load, normal cruising horsepower.

that moderate turbulence may be expected under 4,000 ft. Thus we see that time, fuel consumption, and weather conditions must all be

U.A.L. Trip Weather Analysis

Airway: LG-CG Trip: 1-11-40 Departing 900A Date: 3-11-40

Air Mass Analysis, Including Clouds (Top, Type, Etc.): CP WITH VARIABLE CLDNS
CG ACCT LOW MOVING IN FROM NW.

Fronts: Type: WARM OCCLUDED Intensity: MODERATE
Location: E OF CG Movement: E

Precipitation: (Location & Type): R-CG
Thunderstorms: (Location & Intensity):

Ice: Type: Severity: Region:

Static: Region:

Term. or Alternate	Time	Expected Cig.		Expected Vis.		Sky	Weather and Obst. to Vis.	Misc.
		Height	Trend	Distance	Trend			
CG	1:00R	3T04T	VAR	2T05	VAR	BROKEN	R- K-	
JO	"	"	"	"	"	"	"	

Meteorologist: MASTERS Captain: MURRAY 1st Officer: LOVETT

FIG. 23.—United Air Lines weather analysis.

considered in the choice of flight altitudes. Unless the navigator is also captain of the plane, the decision as to flight altitude is not his responsibility. If he is not captain, it is the navigator's responsibility to

give information concerning weather, flight time, and fuel requirements to the captain. In this case, the captain probably would elect to clear the flight at 8,000 ft. with the idea of loading enough gas aboard to

TRIP 1 DATE 3-11-40 **FLIGHT PLAN** STATION LG

FROM	TO	MILEAGE	PROCEDURE	ALTITUDE	TEMPERATURE	EST. WIND	MAG. COURSE	CRAB L. or R.	MAG. HEADING	GROUND SPEED	HORSE POWER	EST. FLYING TIME
IG	NK	15	CONTACT	4T	37	270-35	290-240	8R	298-235	140	NC	:10 4
NK	XA	86	"	"	"	"	290	8R		140	"	:35
XA	SV	72	"	"	"	"	290	8R		140	"	
SV	BF	48.5	"	"	"	"	281		231	140	"	:52
BF	MC	74	"	"	"	"	285	4R	289	140	"	:57
MC	UPA	46.5	"	"	"	"	282		282	140	"	
UPA	CV	41	"	"	35	"	280		280	140	"	:36
CV	GO	186	"	"	"	270-36	275	L7	268	145	"	127
GO	FLS	88	"	"	"	"	270		270	145	"	
FLS	CG	20	"	"	"	"	335			150	"	:43 3

ALTERNATE FLIGHT PLAN

ESTIMATED FUEL CONSUMPTION

	TOTAL FUEL ABOARD (GALS.)	EST. GALLONS TO BE USED THIS LEG OF TRIP	REMAINING USABLE FUEL MINUS 45 MIN. RESERVE	ALTERNATE AIRPORTS
From LG To CG	700	550	75	JO
From To				
From To				
From To				
From To				

Total Flying Time 5:27

Scheduled Flying Time 5:00

Captain MURRAY

First Officer LOVETT

Dispatcher TUTTLE

ATC. INFORMATION

REMARKS—NOTAM

DANOS ATTACHED

NORMAL OPS.

FIG. 24.—United Air Lines flight plan.

ensure arrival if forced to fly the entire trip at this altitude. Perhaps a 3-hr. reserve supply of gas would be carried in addition to the 5,400-lb. indicated requirement. In other words, about 7,200 lb. would be loaded.

United Air Lines Procedure.—On pages 26 to 29 a United Air Lines weather analysis form, flight plan, and flight log are reproduced. The student will find that abbreviations have been used to identify various check points along the route from La Guardia Field (LG) to

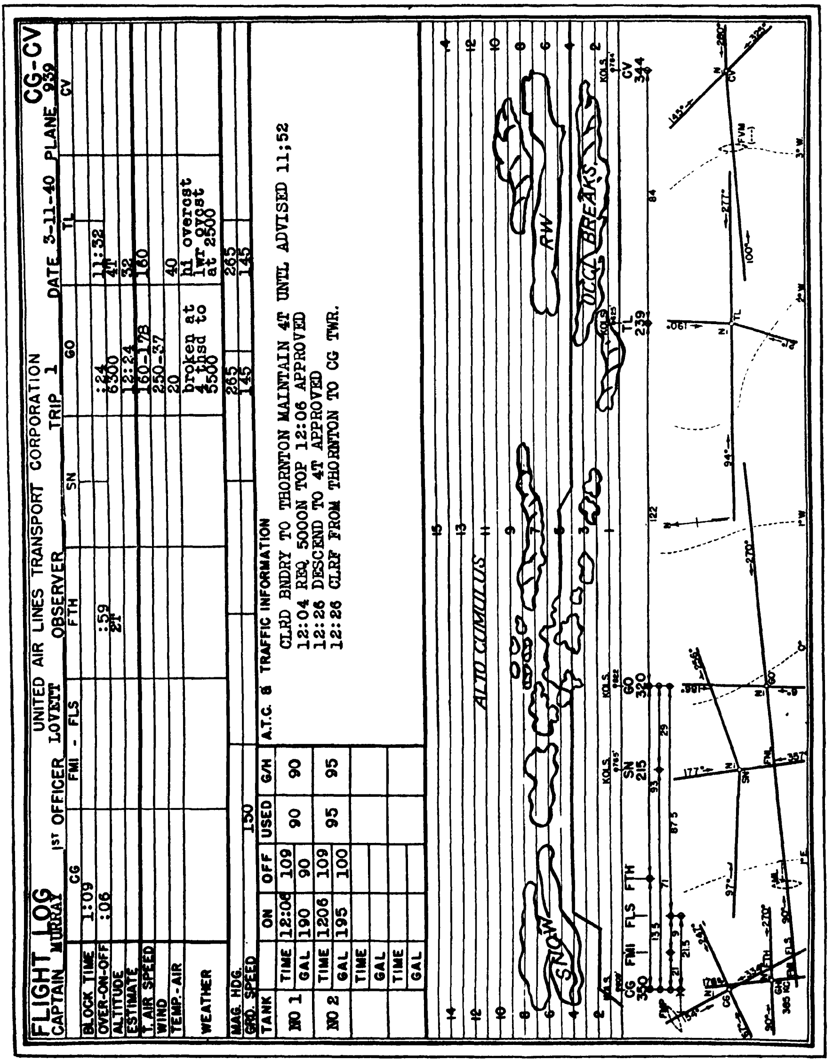


FIG. 25a.—United Air Lines flight log.

Chicago (CG). If regional aeronautical charts are at hand, these check points may be identified by stepping off the mileages between them as set forth on the flight plan. The winds have been forecast for 4,000 ft., which evidently seemed the most desirable flight altitude for the trip. A careful study of the route will show the student that this altitude is

high enough to give safe clearance above the mountains in New York and Pennsylvania. Attention is called to the column in the flight plan labeled Magnetic Course. This is contrary to the basic procedure we

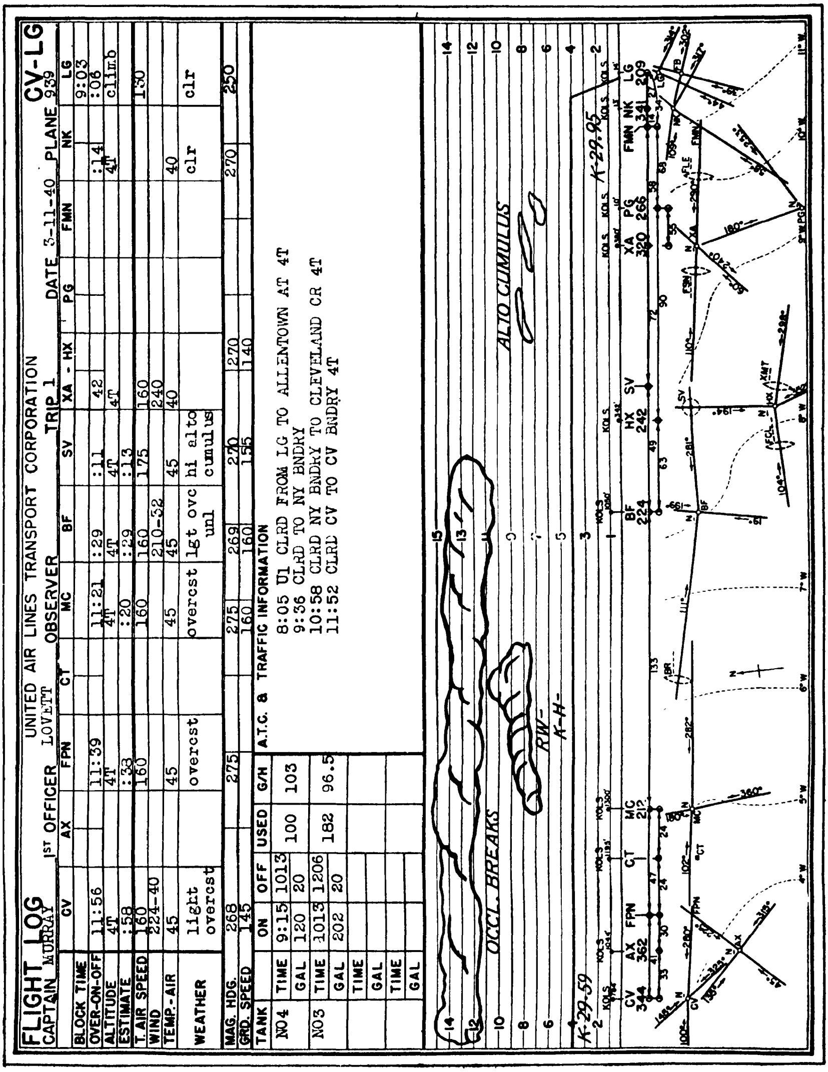


FIG. 25b.—United Air Lines flight log.

have set up for the student. This does not mean that a flight-time analysis cannot be drawn up using magnetic track directions and magnetic wind directions. However, inasmuch as the current practice is to report and forecast winds in true directions, long-range navigators use true directions for tracks as well.

Form W-385—Rev. 8-1

TRANSCONTINENTAL & WESTERN AIR, Inc.
Meteorological Department

AIRWAY and TERMINAL FORECAST

To LL 2 3 4 5

Issued by KC for the twelve hour period from 11P to 11A Date of Issue: MARCH 19 1942

Synoptic Conditions: DEEP TROUGH OF LOW PRESS THRU KANS AND THE PANHNDLS MOVG EWO APPROX 25MPH WILL MOVE TO NERN OKLA BY END OF PRO STP NPP CONDITIONALLY UNSTABLE OVR AWY

Sector: KC-CG KC-LS

11P	4A-11A				Time
HBRKN LCLBRKN	BRKN V OVC				State of Sky
LCLY 80/120	70/120				Base and Top
	LCL 25/45				Base and Top
					Base and Top
LCL RW	RW T				Weather
					Visibility
LGT IN CLDS	LGT IN CLDS				Ice
LGT 0/30	LGT 0/45				Turbulence

Remarks:

Sector: LS-PT

11P	4A-11A				Time
CLR	HBRKN				State of Sky
					Base and Top
					Base and Top
					Base and Top
					Weather
	K 3				Visibility
					Ice
					Turbulence

Remarks:

Sector:

					Time
					State of Sky
					Base and Top
					Base and Top
					Base and Top
					Weather
					Visibility
					Ice
					Turbulence

Remarks:

TERMINAL FORECAST

Terminal: KC LN

11P	12M	3A	6A	9A-11A	Time
HBRKN	BRKN	BRKN	BRKN	OVC	State of Sky
	60	50	20	20 V 15	Ceiling
		RW T VCNTY	RW	S	Weather
				S 3	Visibility

Terminal: LS CA

11P	3A	6A	8A-11A		Time
HOVC	BRKN	BRKN	BRKN		State of Sky
	60	50	45		Ceiling
		OCNL RW	RW T VCNTY		Weather
					Visibility

Terminal: ID DY

11P	5A	7A	9A-11A		Time
CLR	HBRKN	HBRKN	HBRKN		State of Sky
					Ceiling
					Weather
K 4	K 2	K I V	K 3		Visibility

Terminal: CO

11P	1A	4A	7A	9A-11A	Time
CLR	CLR	CLR	HBRKN	HBRKN	State of Sky
					Ceiling
					Weather
K 5	K 2	K F I V	K F 1/4 V	K H I 1/2 V	Visibility

WEA KC 1130PMC

Terminal:

					Time
					State of Sky
					Ceiling
					Weather
					Visibility

Meteorologist ______ Time ______

FIG. 26a.—T.W.A. airway and terminal forecast.

TWA Flight Forms.—Reference to Figs. 26*a* and 26*b* will show that there is little standardization in the matter of flight forms. Inasmuch as flight-plan procedure varies with each air line, the problem of company

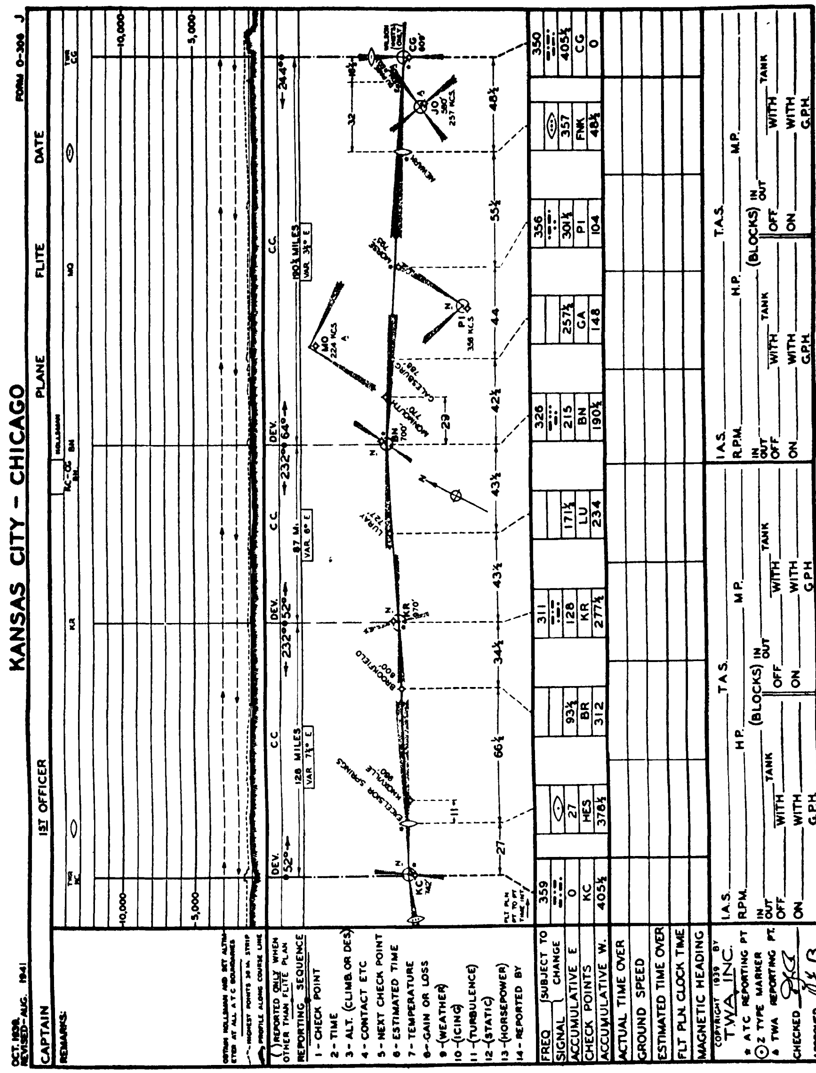


FIG. 26*b*.—T.W.A. route chart.

details may well be left until such time as the student becomes directly interested in them; he should concentrate now on the basic work involved.

Problem: Using the following weather forecast and flight-time analysis form, draw up a plan of flight from Kansas City to Albuquerque. DC-3 equipment

is to be flown at a normal cruising horsepower of 550 per engine. Fuel consumption is to be calculated on the basis of 95 gal. per hour.

MID-WEST AIR, INC.

WEATHER FORECAST NO.____

FILED 1800 GCT
PLACE K.C.
DATE 4-15-43

KANSAS CITY TO ALBUQUERQUE MAP 1200 GMT

TRIP 1,000 TRACK VARIOUS DEPARTURE TIME 1900 GCT

STD. FORM A1-5A

ZONE ENDING	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	WINDS 1000 FT.	WINDS 4000 FT.	WINDS 8000 FT.	WINDS 12000 FT.
WICHITA	SCATTERED CUMULUS	4 Cu 35	9500	NIL	12,000		210-16	240-20	260-25
AMARILLO	BROKEN Cu	7 Cu 55	12-18,000	3 Ac 15,000	13,000		200-20	220-25	240-30
ALBUQUERQUE	SCTD THUNSTMS	8 Cu Nbs.	12-25,000	5 Ac 18,000	15,000			240-30	270-40

TERMINALS	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	SURFACE WIND	VISIBILITY		
K.C	SCTD.	1/10 Cu 2500	6000	NIL	12,000	180-20	6		
WD.	SCTD.	5 Cu 20	9000	NIL	13,000	180-20	9		
AQ.	SCTD. THOUSTM.	8 Cu 15	12-25,000	4 Ac-18,000	15,000	160-25	UNL		
AB	HI. SCTD.	NIL	-	3 Ac-12,000	15,000	310-15	UNL		

REMARKS:

SCTD R Tc to Ag Mstly just N of route

METEOROLOGIST White

FIG. 27.—Weather forecast: Kansas City–Albuquerque.

The flight-time analysis work performed so far has enabled the navigator to determine the most advantageous flight altitude, approximate flight time, and required fuel load. It would seem that with this information the plane might safely load its passengers and depart, but

two very important possibilities have been overlooked. The winds may prove to be stronger than and different in direction from those forecast, and a longer flight and greater gas consumption may result. Secondly,

PLANE____________ **MID-WEST AIR, Inc.** DATE____________

FLIGHT NO.____________ **FLIGHT ANALYSIS** DEPT.____________

BASED ON FORECAST____________

4,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

8,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

12,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

FLIGHT PLAN

ALTITUDE

END OF ZONE	ALT	T H	G.S.	TIME	ACCUMULATIVE		GAS ABOARD
					TIME	FUEL	
		TOTALS					

Gas Reserve____________

Alternate:____________

Capt. Signature____________ Nav. Signature____________

FIG. 28. Flight analysis and flight plan: Kansas City–Albuquerque.

although the plane may arrive at its destination on time, weather conditions may prevent an immediate landing and in some cases it may be necessary to proceed to an alternate airport. Both these unknown factors

make it imperative that the navigator when planning the flight select one or more alternate airports where weather conditions are certain to remain

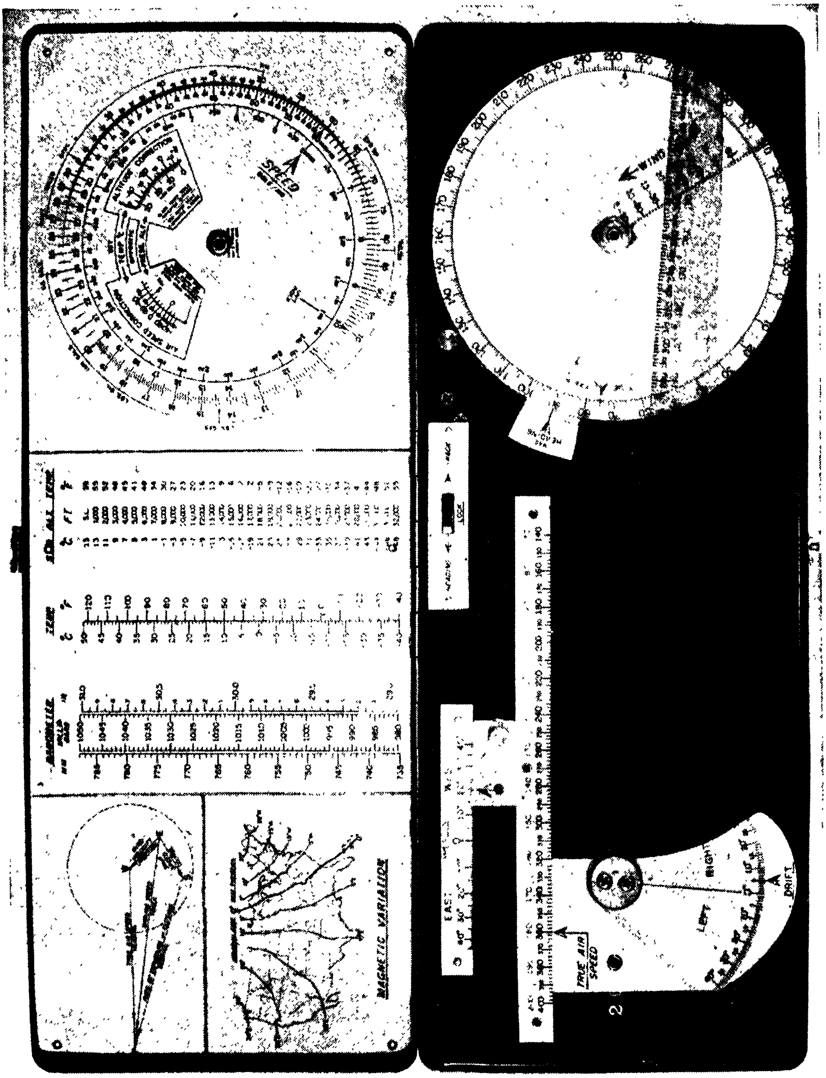


FIG. 29.—Cox & Stevens Mark NW computer.

above the minimum required for landing and that he load a sufficient amount of gas to enable him to reach the most distant alternate.

The navigator, then, will study his charts and weather reports in order to ensure meeting these requirements. Needless to say, extra gas should be carried if at all possible. In order to establish the requisite

gas load, the ground speed from the destination to the farthest alternate airport must be calculated since this, of course, will depend on the wind and weather conditions in that part of the country.

Ground-speed Computer.—In working out the preceding flight-time analyses, the student has been solving for ground speed by working out

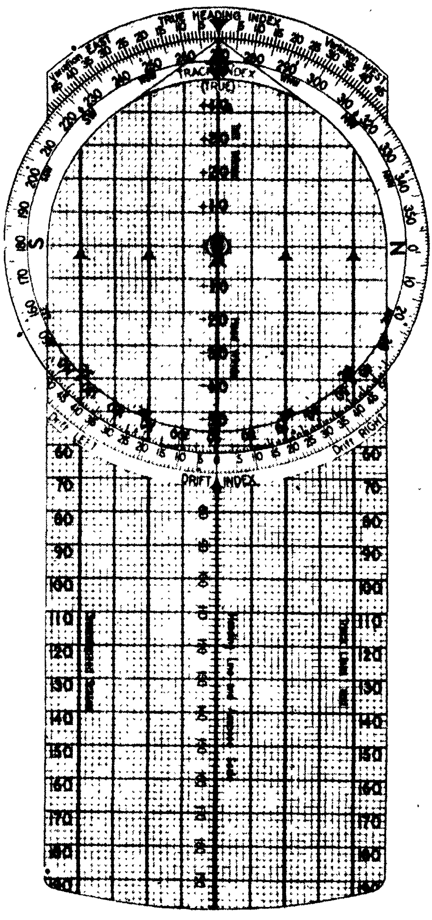


FIG. 30.—Dalton Mark VII computer.

the triangle of velocities graphically. This is good practice; frequently in ocean flying boats high-wind problems come up that are most easily solved on the chart without recourse to a computer. The method is inconvenient, however, unless a chart table is available; if a computer is at hand, it will generally save time and much mental effort. There are various types of navigational computers on the market, all of which are more or less adaptable to this type of work. Some, in solving the

triangles, actually show the sides and angles much as they were shown in the graphic solutions. Others give the correct answer if certain precepts are followed but do not show the triangle itself. The author has a distinct preference for the former type, among which may be classified the popular Cox & Stevens Mark NW and the Dalton Mark VII illustrated on pages 34–35 and the Kueffel & Esser Model E-6B or J.

If the student does not have one of these at hand, he is urged to cut out the computer in the pocket in the back of this book and assemble it as in the sketch (Fig. 31). The time necessary to assemble the units will be more than regained in working out the following flight-time analysis problems.

Method of Use.

Given: Track desired 90°.
Wind—300°, 30 m.p.h.
TAS—175 m.p.h.

Required: The ground speed.

Procedure: Rotate the disk until 90° lines up with point X on the ground-speed scale. This establishes the track. Place the upper left-

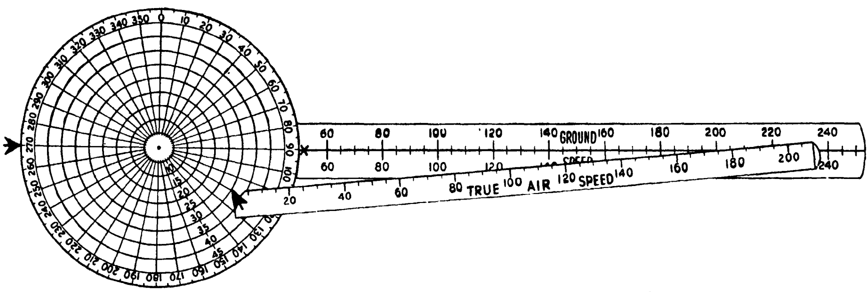


Fig. 32.—Computer solution for ground speed.

hand corner of the air-speed scale 30 units away from the center of the disk (away from 300°). Keeping that point of the air-speed scale in position, move air-speed scale up until 175 m.p.h. crosses the center line of the ground-speed scale. Read the ground speed shown at the point of crossing: 201 m.p.h. (see Fig. 32).

Given: Track desired 130°.
Wind—40°, 40 m.p.h.
TAS—160 m.p.h.

Required: The ground speed.

Procedure: Rotate the disk until 130° lines up with point X on the ground-speed scale. This establishes the track. Place the upper left-hand corner of the air-speed scale 40 units away from the center of the disk (away from 40°). Keeping this point of the air-speed scale in position, move the air-speed scale up until 160 m.p.h. crosses the center line

of the ground-speed scale. Read the ground speed shown at the point of crossing: 154 m.p.h. (see Fig. 33*a*).

Ground-speed Computer: Alternative Method of Use.—Flight analysis ground speeds may be determined more rapidly and just as accurately as follows: Rotate the disk so as to place the desired track at the left arrowhead instead of at *X*. Place the air-speed arrowhead the

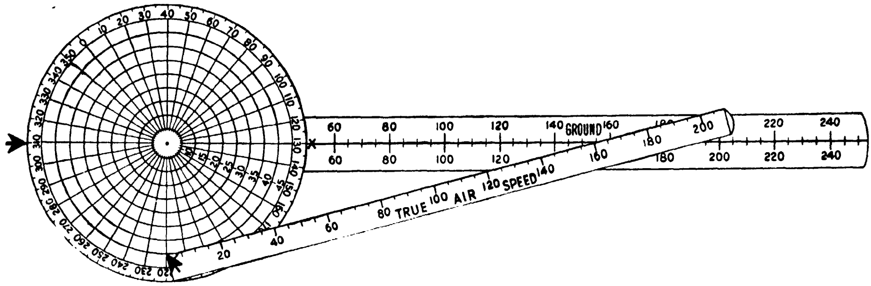


FIG. 33*a*.—Computer solution for ground speed.

required number of units away from the center of the disk *toward* the wind direction.

The problem already illustrated in Fig. 33*a* is shown reworked in this manner in Fig. 33*b*.

The Navigator's Circular Slide Rule.—The tedium of repeated arithmetical computations incidental to the analysis of flight times may be materially reduced if the navigator becomes proficient in the use of a circular slide rule. A great many types of problems may be solved on this

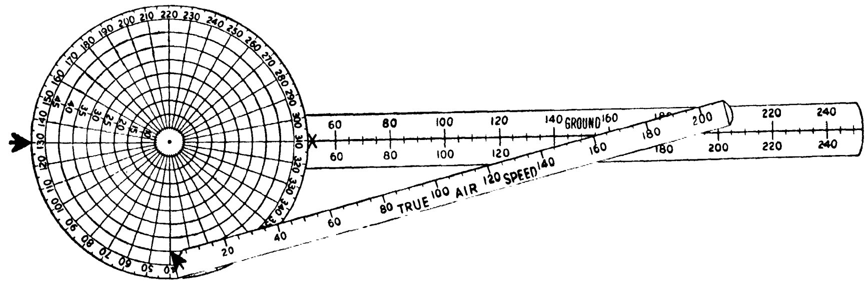


FIG. 33*b*.—Determining ground speed—alternative method.

instrument, but to become truly adept in its use would require considerable study. In the practice of navigation, problems involving multiplication, division, and proportion arise continuously and the speed and ease with which these problems are solved with a slide rule more than justify the following brief instruction in its use.

A cutout model of a slide rule is in the pocket in the back of the book. It should be cut out carefully and assembled according to the sketch (Fig. 34).

The two concentric scales are idèntical. Number 100 on the rule may be used as 1, 10, 100, 1,000, etc. If this figure, the first on the scale, is considered to be 1.0, the next figure becomes 1.1, the next 1.2, 15 becomes 1.5, 20 becomes 2.0, 60 becomes 6.0, and 90 becomes 9.0. If this first figure is assumed to be 10, the numbers on the scales have values as shown. If the starting point is considered to be 100, 11 becomes 110, 12 becomes 120, 14 becomes 140, etc. For our purpose this is a sufficient analysis of the scale values.

Use of the Rule in Performing Multiplication.—The scale is so arranged that multiplication may be performed by adding the portion

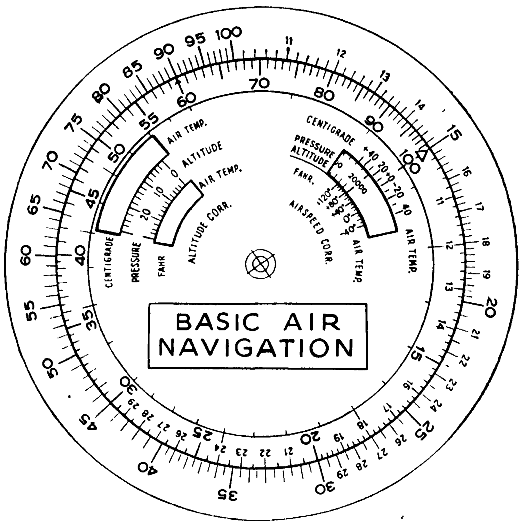


FIG. 35.—Performing multiplication with circular slide rule.

of the inner scale (representing the second number of a multiplication problem) to the portion of the outer scale that represents the first number. For example, 15 is to be multiplied by 6.

Procedure: Rotate the inner disk until 1.0 is in line with the number 15 on the outer scale. The answer, 90, is found on the outer scale *opposite* 6.0 *on the inner scale* (see Fig. 35).

PROBLEMS

1. The ground speed of an aircraft is 160 m.p.h. How far will the plane travel in 4.5 hr.?

Procedure: Rotate the inner disk until 1.0 is in line with the number 16 (160) on the outer scale. The number shown on the outer scale *opposite* 4.5 *on the inner scale* is the answer: 720 miles (see Fig. 36).

2. The ground speed is 205 m.p.h. How far will the plane travel in 7.1 hr.?

Procedure: Rotate the inner disk until 1.0 is opposite the number 20½ (205) on the outer scale. The number shown on the outer scale *opposite* 7.1 *on the*

inner disk is the answer: 14.55 (1,455 miles). In this case the portions of the scales were so large that they overlapped when added together, but the method employed in the solution is the same for this problem as for the previous ones (see Fig. 37).

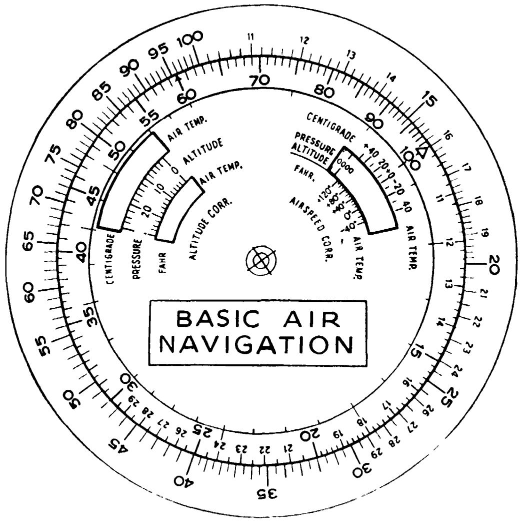


FIG. 36.—Slide-rule multiplication.

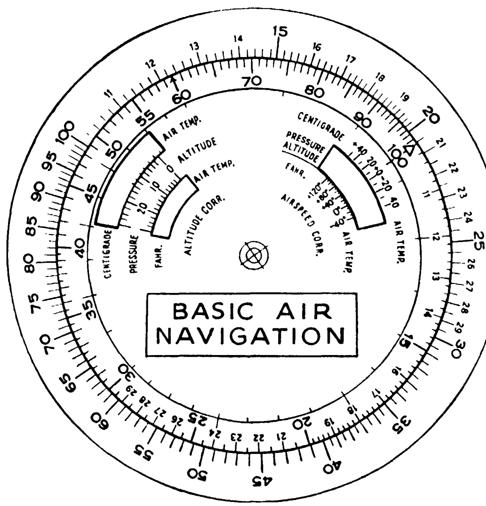


FIG. 37.—Slide-rule multiplication.

Use of the Rule in Problems of Division.—Multiplication was achieved by adding a portion of the inner scale to a portion of the outer scale; division is achieved by subtracting a portion of the inner scale from a portion of the outer scale.

PROBLEMS

1. Divide 60 by 5.

Procedure: Rotate the inner scale until 5.0 is in line with the number 60 on the outer scale. The number on the outer scale *opposite* 1.0 *on the inner scale* is the answer: 12. This is shown graphically in Fig. 38.

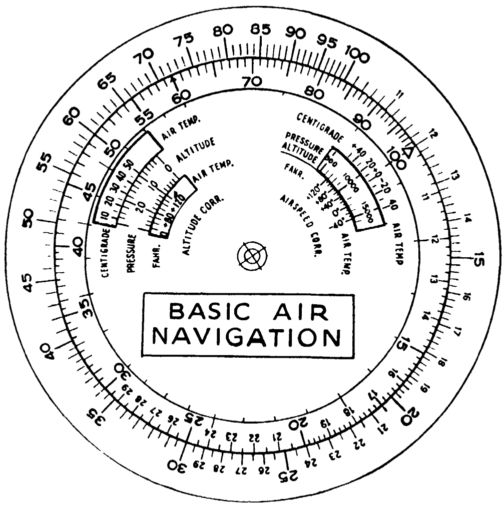


FIG. 38.—Performing division with circular slide rule.

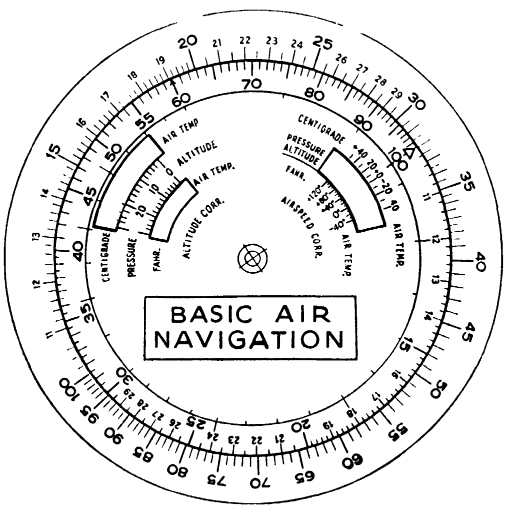


FIG. 39.—Slide-rule division.

2. How long will it take a plane to fly 480 miles at a ground speed of 150 m.p.h.?

Procedure: Rotate the inner scale so as to place 15 (150) underneath 48 (480) on the outer scale. The number on the outer scale *opposite* 1.0 *on the inner scale*

is the answer: 32 (3.2 hr.). The position of the decimal point must be determined by inspection of the problem (see Fig. 39).

3. The distance between Pittsburgh and Columbus is 158 miles. The ground speed according to the flight-time analysis is 185 m.p.h.

Required: The flight time.

Procedure: Rotate the inner scale until 185 (18½) is opposite 158 (15.8) on the outer scale. The number on the outer scale *opposite* 1.0 *on the inner scale* is the answer: approximately 85.5 (0.855 hr.) (see Fig. 40).

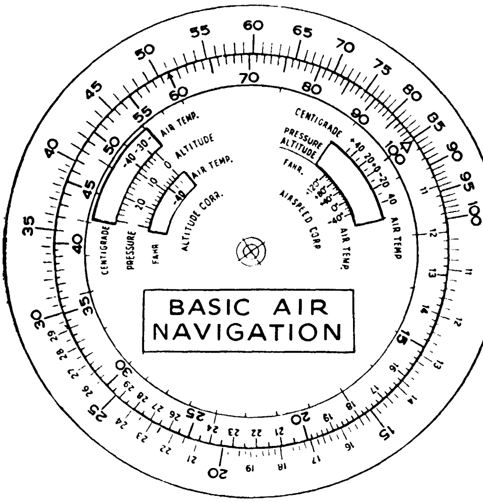


FIG. 40.—Slide-rule division.

Use of the Rule in Problems of Proportion.—In flight-time analysis problems it is rather more convenient to work in hours and decimal parts of an hour than in hours and minutes since this simplifies the work of adding up the flight times for the various legs. In flight the navigator usually thinks of elapsed times in terms of hours and minutes, and the problems involving hours and minutes are most easily solved by proportion.

PROBLEMS

1. The distance between Pittsburgh and Columbus is 158 miles, and the recorded flight time is 51 min.

Required: The ground speed made good.

Procedure: Rotate the inner disk until 51 is opposite 158 on the outer scale. The number *opposite* 60 (*minutes*) *on the inner scale* is the answer: approximately 186 m.p.h. The problem may be restated as follows: 51 min. bears the same relationship to 158 as 60 does to 186, the distance made good per hour (see Fig. 41).

2. A plane flies a distance of 200 miles in 1 hr. 12 min.

Required: The ground speed.

Procedure: Rotate the inner disk until 72 min. is opposite 200 on the outer scale. The number on the outer scale *opposite* 60 *on the inner scale* is the ground speed, or distance covered in 60 min.: approximately 167 m.p.h. (see Fig. 42).

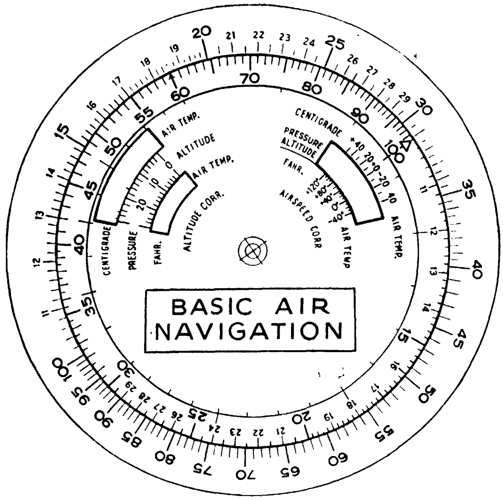


FIG. 41.—Solving problems of proportion with circular slide rule.

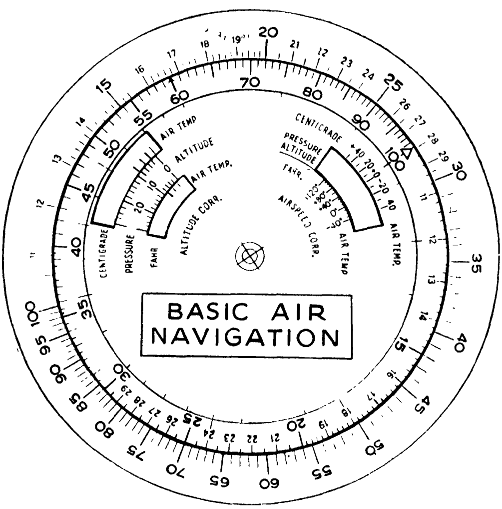


FIG. 42.—Solving proportion problem with slide rule.

3. According to the flight-time analysis a ground speed of 172 m.p.h. will be made in a zone 145 miles in length.

Required: The flight time through the zone in minutes.

Procedure: Rotate the inner disk until 60 is *opposite* 172 *on the outer scale.* Read the number on the inner disk *opposite* 145 *on the outer disk:* 51 min. approximate flight time (see Fig. 43).

Summary.—The rule for working problems of the preceding type is as follows: Use the inner scale for minutes of flight; use the outer scale for mileages. If this is done, miles per hour will always be found or placed opposite 60 min. according to the type of problem.

If the student is pressed for time, it is suggested that he concentrate on solving all problems by proportion and omit further study of multiplication and division. The problem, for example, as to how far an aircraft will travel in 3 hr. at a ground speed of 150 m.p.h. may be solved by proportion. Set 60 (minutes) on the inner scale opposite 150 on the

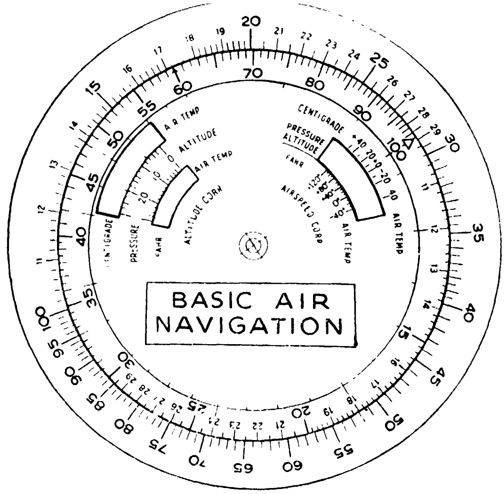


FIG. 43.—Solving proportion problem with slide rule.

outer scale, and read the answer on the outer scale opposite 180. Likewise, the problem as to the flight time required to traverse a 200-mile zone at a ground speed of 180 m.p.h. may be solved by placing 60 opposite 180 on the outer scale and reading the answer in minutes on the inner scale opposite 200.

SLIDE-RULE PROBLEMS

In the following problems determine the distance; solve by multiplication:

	Distance, miles	Ground speed, miles per hour	Flight time, hours
1		155	3.1
2		175	1.2
3		130	0.9
4		210	2.6
5		162	5.7

In the following problems determine the flight time in hours and tenths of hours; solve by division:

	Distance, miles	Ground speed, miles per hour	Flight time
6	670	132	
7	1,792	148	
8	912	156	
9	405	215	
10	126	170	

In the following problems find the ground speed to the nearest mile; solve by proportion:

	Distance, miles	Ground speed, miles per hour	Flight time
11	310		2 hr. 12 min.
12	490		2 hr. 56 min.
13	256		1 hr. 10 min.
14	140		46 min.
15	835		6 hr. 20 min.

In the following problems, solve for flight time by proportion:

	Distance, miles	Ground speed, miles per hour	Flight time
16	97	194	
17	88	212	
18	52	150	
19	200	181	
20	165	142	

21. Using Chart 3060*b*, and the following weather forecast and flight-time analysis sheet, draw up a flight plan from New Orleans to Richmond, Va. DC-3 equipment is to be flown, 550 hp per engine is to be developed, and the flight is to proceed via the airways.

Though the weather appears good, calculate the fuel requirement assuming that part of the trip will be made on instruments and that Washington, D.C., and Norfolk, Va., are the two possible alternates. Select for the flight the best *single* flight altitude. Base the fuel requirement on the assumption that $\frac{5}{10}$ lb. of gas will be required to develop 1 hp. per hour; this is known as using a *specific fuel consumption* of 0.50. A gallon of high-octane gas weighs approximately 5.8 lb.

It is customary at this point to explain radius of action in general and its application to the problem of reaching alternate airports in

particular. Discussion of this subject will be omitted for the present. In radius-of-action problems the plane is usually assumed to be head-

MID-WEST AIR, INC.

WEATHER FORECAST NO._____

FILED 0400 GMT
PLACE NEW ORLEANS, LA.
DATE 4-16-43

CAPT NC 5000 Dc3 MAP 0000 GMT

TRIP 1500 TRACK NO-RW DEPARTURE TIME 0600 GMT

STD. FORM A1-8A

ZONE ENDING	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	WINDS 3000 FT.	WINDS 5000 FT	WINDS 7000 FT.	WINDS 12000 FT.
NO-MS 125	SCATTERED	2/10 Cu 2000'	3500'	NIL	9000+	110-14	160-16	180-20	
MS-XW 286	SCATTERED	3/10 Cu 2200'	3500'	NIL	9000+	140-14	160-16	180-20	
XW-AG 422	CLEAR	NIL	NIL	NIL	9000+	140-14	200-18	220-20	
AG- 622	"	"	"	"	"	180-10	220-18	230-22	
-RW 898	BROKEN	3/10 Cu 2500'	4000'	6/10 AC 14,000'	9000+	230-20	230-20	260-26	
RW-NW 73	SCATTERED	2/10 Cu 2000'	3500'	3/10 AC 12,000'	9000+	230-20	230-20	260-24	
RW-WA 96	BROKEN	4/10 Cu 2500'	4000'	6/10 AC 14,000'	9000+	240-18	230-20	260-26	

TERMINALS	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	SURFACE WIND	VISIBILITY		
RW	BROKEN	3/10 Cu 2500'	4000'	6/10 Ac 14,000'	9000+	210-10 Mi.	10 Miles		
WA	BROKEN	4/10 Cu 2500'	4000'	7/10 Ac 14,000'	9000+	260-16 Mi.	10 Miles		
NW	SCATTERED	4/10 Cu 2000'	4000'	NIL	9000+	210-12 Mi.	8 Miles		

REMARKS:

High pressure area centered over Bermuda causing southerly and south westly winds along route; entire flight through returning NPc air mass. Scattered to broken cloudiness with fair visibility and unlimited ceilings entire route. Slight turbc in lower levels.

METEOROLOGIST *Jones*

Fig. 44.—Weather forecast: New Orleans–Richmond.

ing for an airport where weather conditions are far below the minimums required for landing. In this predicament the pilot determines how long he may continue toward his destination before turning off to

reach his alternate. Flight clearance is granted commercial air-line planes only when there is positive assurance that alternate-airport

MID-WEST AIR, Inc.

FLIGHT ANALYSIS

PLANE__________ DATE__________

FLIGHT NO.__________ DEPT.__________

BASED ON FORECAST__________

3,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

5,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

7,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

FLIGHT PLAN

ALTITUDE

END OF ZONE	G.S.	TIME THRU ZONE	ACCUMULATIVE		GAS ABOARD
			TIME	FUEL	
		TOTALS			

Gas Reserve__________

Gas weight per gallon:__________

Alternate: __________ Time to point of no return__________
(allowing ____ reserve)

Capt. Signature__________ Nav. Signature __________

FIG. 45.—Flight analysis and flight plan: New Orleans–Richmond.

weather conditions will remain at or above landing minimums. On a flight of this nature sufficient gas must be carried to enable these planes to reach their most distant alternate *after having reached* their destination,

and the problem as to *how far* out along the track they may proceed seems rather academic.

With the flight plan approved and clearance granted, the student is now ready to consider the problems of the flight itself. Maintenance of proper flight altitude along the airway becomes one of the first of these problems and requires a sound knowledge of the use of altimeters. The study of these and flight instruments in general will be taken up following a discussion of the preflight work of the ocean navigator.

CHAPTER III

PREFLIGHT DUTY OF THE OCEAN NAVIGATOR

The preflight work of the ocean navigator, like that of the domestic pilot-navigator, calls for consideration of wind conditions, tracks, air speeds, distances, and fuel consumptions. These enter into his analysis of possible flight time, and weather and terrain conditions influence his recommendation of flight altitudes. Where his work differs from the work of the domestic pilot-navigator, it differs in point of emphasis rather than in principle. Much more consideration, for example, is given to possible fuel consumptions. In long ocean flights it is impossible as a rule to vary the horsepower and air speed except within narrow limits in order to make schedule. The ocean navigator, therefore, must concern

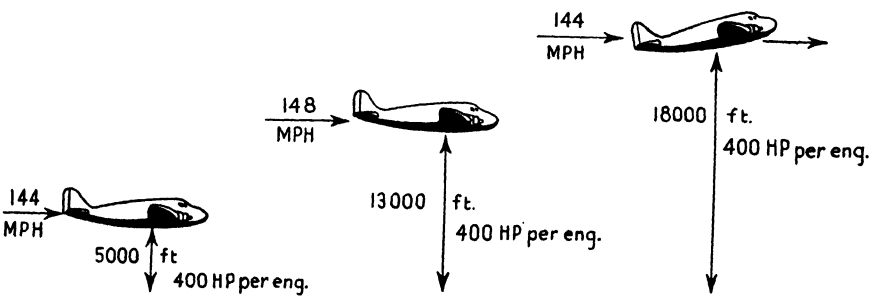


FIG. 46.—Air speed vs. altitude.

himself with the most economical air speeds since these result in greatest fuel economy and safety and largest pay loads.

Horsepower vs. Fuel Economy.—Every type of aircraft engine functions most efficiently under certain specified operating conditions that involve horsepower, revolutions per minute (r.p.m.), and fuel-air mixture. Under other operating conditions the specific fuel consumption is greater. If, for example, horsepowers in excess of those recommended are developed, an increase in specific fuel consumption may become necessary to avoid detonation. For the development of very low horsepowers at low r.p.m., the mixing of the fuel and air is less than satisfactory and results in a net horsepower loss per unit of fuel.

Air Speed vs. Horsepower.—At a given flight altitude more air speed may be achieved by increasing the horsepower, but reference to Fig. 13 (page 14) shows clearly that twice the air speed is not achieved by

doubling the horsepower. For a given horsepower, a plane ordinarily makes more air speed in high, thin air than it does close to the surface, where the air resistance is greater. Each type of plane, however, has a critical performance altitude above which its air speed drops even though the horsepower remain constant. At such a critical altitude decreased air speed results from having to increase the angle of attack in order to maintain level flight. In other words, the nose of the plane is raised and the plane offers more resistance to the air stream.

Air Speed vs. Wind Conditions.—A plane cruising at 100 m.p.h. in a 100 m.p.h. head wind makes no headway toward its destination; if the air speed is increased to 110 m.p.h., the plane makes 10 m.p.h. over the ground. If this additional speed enables the plane to reach its destination, a net gain results even though extra fuel be used for the purpose.

On occasion a greatly increased air speed may enable an aircraft to get through a high-wind area that otherwise would have stopped it completely. For this reason air speeds are usually increased in head winds; if economy becomes necessary, air speeds may be reduced in tail winds. The following problem will serve to emphasize wind-air-speed economy.

Problem: A plane is flying into a 75 m.p.h. head wind. The following air speeds are achieved by developing the horsepower shown below. The specific fuel consumption is 0.5.

Horsepower	Air speeds, miles per hour	Ground speeds, miles per hour	Fuel consumption per mile
800	144	69	5.77
1,000	164	89	5.60
1,200	180	105	5.72

This problem deals with an exceptionally high wind; but it is intended to illustrate the point that, for a given wind and plane, there is a most economical cruising air speed. In large ocean-flying-boat operation, fuel-consumption curves are used that furnish optimum air speeds for head- and tail-wind conditions. Since the fuel consumption per hour is higher (owing to increased air speed) flying into a head wind, these curves are ordinarily used in flight planning.

Air Speeds for Long Flights.—The ocean navigator must make himself familiar with the particular performance data applicable to the type of aircraft to which he is assigned. One fact will become evident at once. Very conservative cruising air speeds are used on all but the very shortest flights. Before commencing the flight analysis, the naviga-

tor should consult the captain as to whether he wishes the analysis based on high, medium, or long-range speeds.

Air-speed data will be made available in some such form as that shown in Fig. 47. The graph gives speeds to be used at various possible flight altitudes and distances out from the base.

Problem: Air speeds are required for an 1,800-mile flight divided into weather zones of 300, 350, 300, 400, and 450 miles.

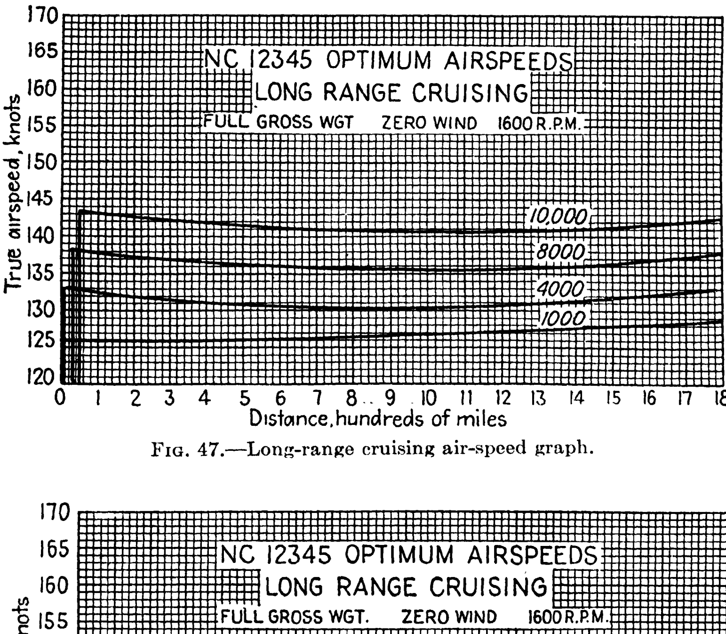


FIG. 47.—Long-range cruising air-speed graph.

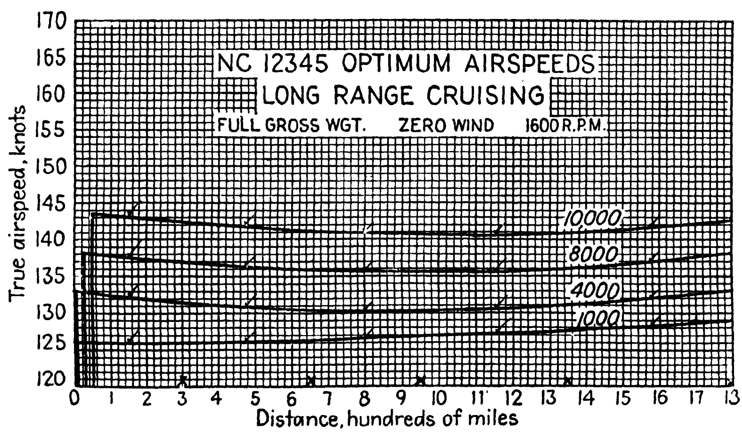


FIG. 48.—Determining air speeds for route zones.

Procedure: The accumulative zone distances (300, 650, 950, 1,350, and 1,800) should be stepped off across the bottom of the air-speed graph. Air speeds for each zone are taken from the *center* of each zone, as shown in Fig. 48.

It is of interest to note that air speeds (with the exception of the 1,000-ft. speeds) decrease a few hours after take-off. Higher air speed is required at the beginning of a flight because a heavily loaded plane must be flown somewhat faster to maintain altitude.

Problem: What air speeds should be used on a 1,600-mile flight divided into weather zones as follows: 200, 200, 400, 500, and 300 miles?

Fuel-consumption Graph for Ocean Flights.—The student is already familiar with the type of fuel-consumption graph shown in Fig. 49.

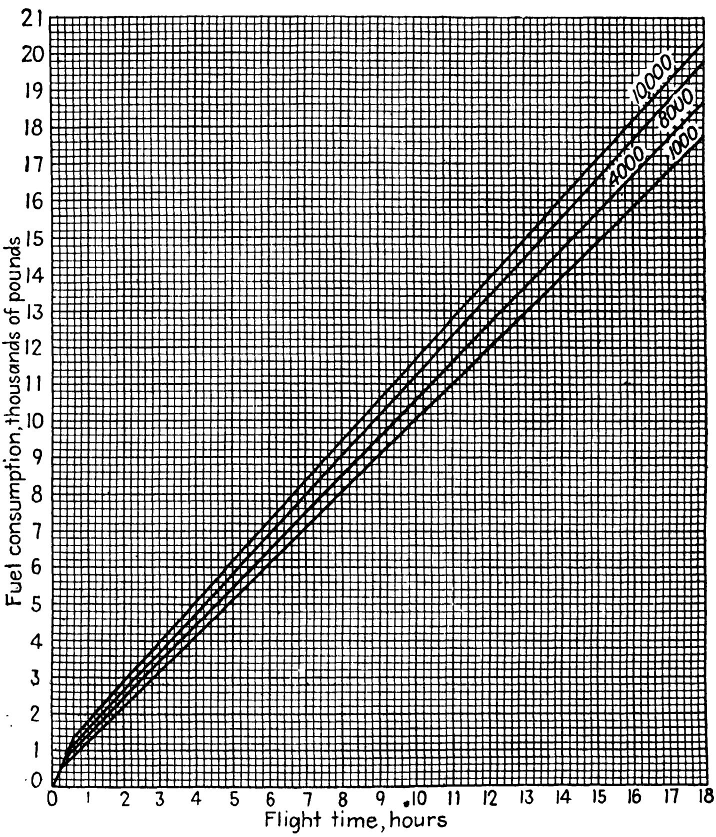


FIG. 49.—NC 12345 fuel-consumption graph for use with long-range cruising air speeds. Full gross weight, zero wind, 1,600 r.p.m.

The vertical axis represents gas in thousands of pounds; the horizontal axis represents elapsed flight time. At 1,000 ft. this plane burns 11,000 lb. in 11 hr. In 11 hr. at 4,000 ft. it burns 11,600 lb.

Problem: How much gas is required for the following flights?

	Altitude, feet	Time, hours
1	1,000	14.1
2	4,000	13.3
3	8,000	12.5
4	10,000	12.1

Charts Used by the Ocean Navigator.—The Lambert chart already discussed in Chap. II (page 22) is seldom used on ocean flights. The frequent determination of tracks on a long ocean flight is made somewhat

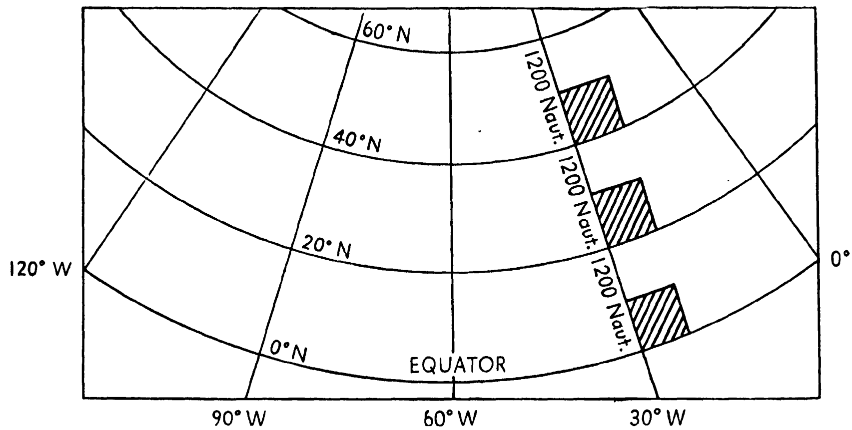


FIG. 50.—Lambert conformal chart.

easier by the employment of the Mercator projection. The following two illustrations are intended to show the essential differences between Lambert and Mercator charts. In each chart, the shaded portions are 600 miles square.

On a Mercator projection all latitude parallels are shown as straight east-west lines and all meridians of longitude are shown as parallel vertical lines. A straight-line track on this projection crosses all meridians at the same angle. Regardless of the length of a given track, it is unnecessary for the navigator to measure it at some mid-meridian.

When the flight distance is comparatively short, a straight line (*AB* in Fig. 52) is drawn between the point of departure and destination, and this suffices for the entire flight. The straight line on a Mercator chart is known as a **rhumb line.** It is not necessarily the shortest distance between these two points, but the ease with which it is determined and employed in flight justifies its use.

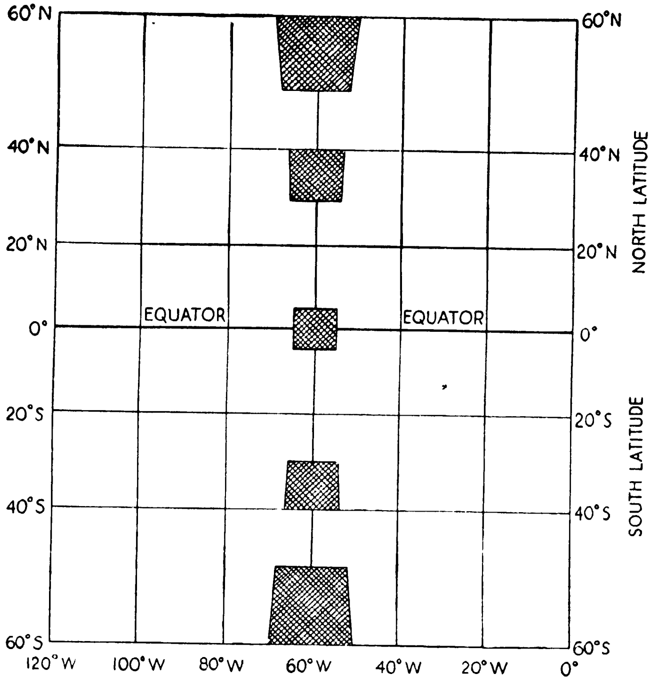


FIG. 51.—Mercator chart.

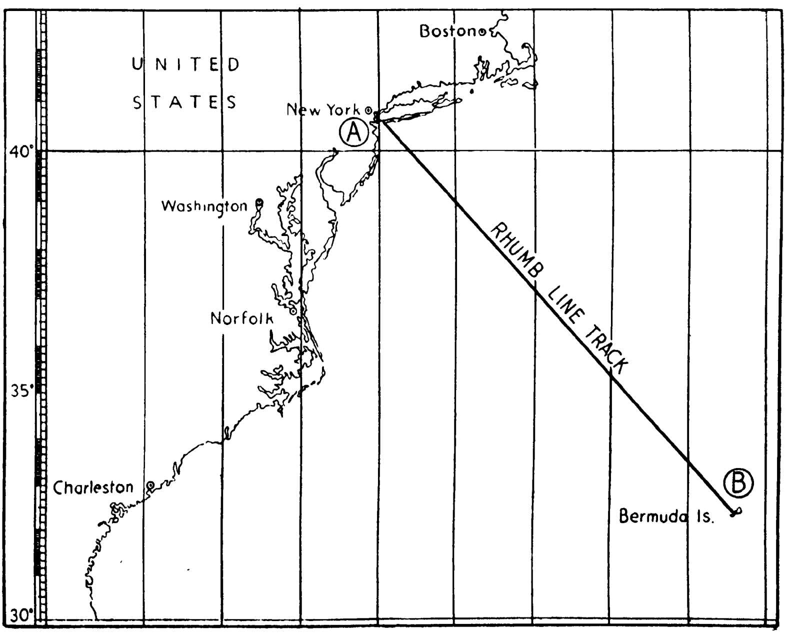


FIG. 52.—Rhumb-line track on a Mercator chart.

Several tracks are shown laid down on a Mercator chart in Fig. 53. These tracks are always measured clockwise from north and may be measured relative to any meridian.

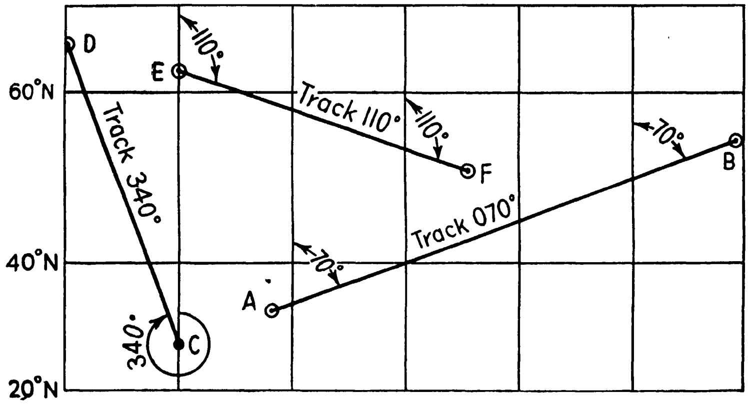


FIG. 53.—Measuring Mercator tracks.

Obtaining Track Distances from a Mercator Chart.—A Mercator chart is essentially a projection of the earth on a cylinder tangent at the equator (see Fig. 54). The student will note that extreme distortion occurs in high latitudes; some distortion, in point of fact, occurs all over the chart. This is of minor importance as far as the navigator's work is concerned because no flat charts can ever represent the round earth without creating some distortion. The important thing to bear in mind is that this distortion is not uniform throughout the chart; for this reason a distance scaled in any given area must be referred to the correct mileage scale for that area.

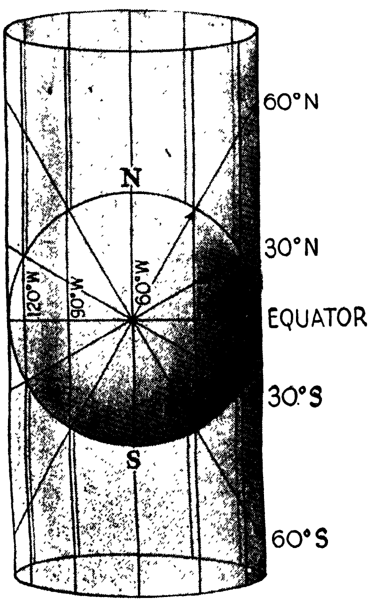


FIG. 54.—Approximate method of projecting the earth on a Mercator chart.

Statute miles are not used in ocean navigation, since these have an arbitrary length of 5,280 ft., a measurement that has no direct relation to angular measure on the earth's surface. The ocean navigator reckons all distances (and ground speeds) in terms of nautical miles of 6,080 ft. A nautical mile is $\frac{1}{60}°$ of a great circle, and a great circle is formed by a plane through the center of the earth as shown in Fig. 55.

Study of this figure will show that the equator is a great circle. The line AB is also a part of a great circle; and, most important of all from a mileage-scale standpoint, the meridians of longitude are great circles. A degree on any of these circles contains 60 nautical miles regardless of the amount of chart used to represent it. Great circles contain 360°, since they go completely around the earth. A meridian of longitude from the equator to the pole contains 90° since this represents one quarter of the circle. This portion of a meridian is subdivided 90 times by latitude parallels running around the earth parallel to the equator. The distance between two successive parallels of latitude measured on the meridian is equal to 60 nautical miles. Since $\frac{1}{60}°$ is equal to one minute of arc (1′), it follows that one minute of latitude is always equal to one nautical mile.

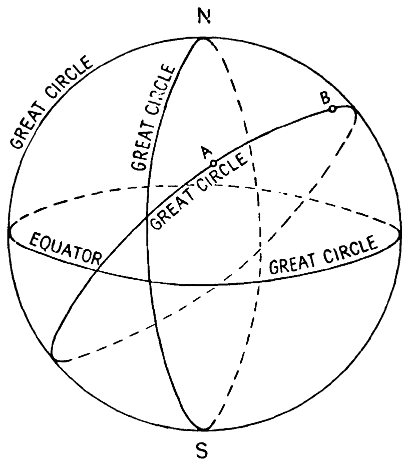


FIG. 55.—Great circles on the surface of the earth.

It is this latitude scale that the ocean navigator uses for the measurement of distances. The distortion inherent in this type of chart projection brings about wide variations in the amount of chart space used to represent a degree of latitude. This is why distances scaled in one portion of the chart must always be measured by means of the latitude scale directly opposite the center of that area. Figure 56 shows the method by which this is done.

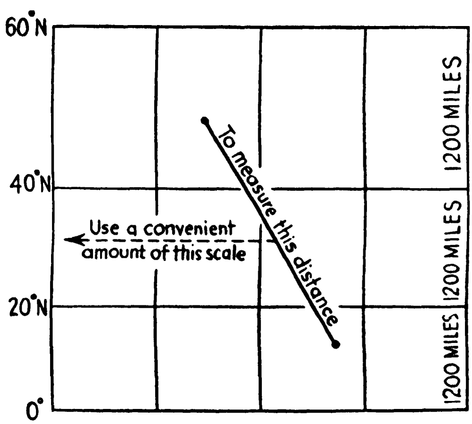


FIG. 56.—Measuring distance on a Mercator chart.

It is recommended that the student familiarize himself with a typical Mercator plotting sheet, such as H.O. VP-102, which may be obtained from the U.S. Hydrographic Office in Washington, D.C. This is the type of chart currently used in the transoceanic service.

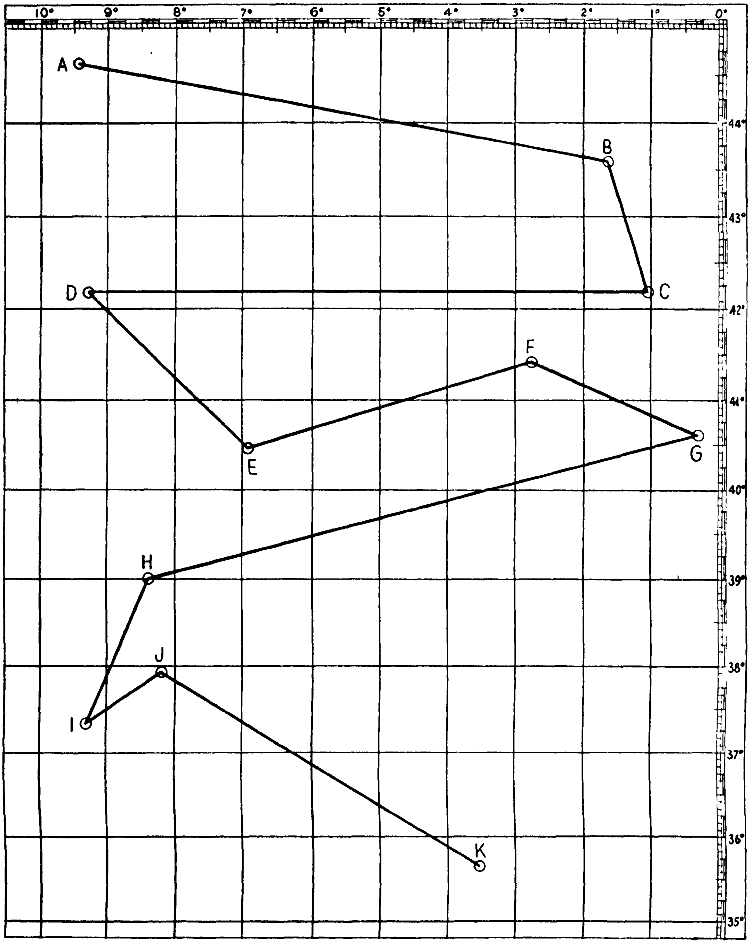


Fig. 57.—Problem in measuring distances on a Mercator chart.

Scale the following distances in Fig. 57: *AB*, *BC*, *CD*, *DE*, *EF*, *FG*, *GH*, *HI*, *IJ*, *JK*.

Great-circle Charts.—Great-circle charts are used principally for flight-planning purposes. They are produced by projecting the earth's surface on a flat plane tangent at some arbitrary point. The principle of construction is shown in Fig. 58, and a small-scale reproduction of a great-circle chart is shown in Fig. 59.

Though the distortion on this chart is so extreme as to render it useless for actual flight purposes, it possesses one great merit. A straight line drawn on this chart represents the shortest possible path between two points. In planning a long-range flight in high latitudes (and in high latitudes alone) some distance is saved by following the great-circle route. In practice the track is first laid down on the great-circle chart; it is then transferred to a Mercator chart by noting and transferring the latitude at which the track crosses every fifth degree of longitude. The actual tracks to be followed are measured on the Mercator projection after transfer, and the distances through the 5° zones are measured against their adjacent latitude scales in the manner just described.

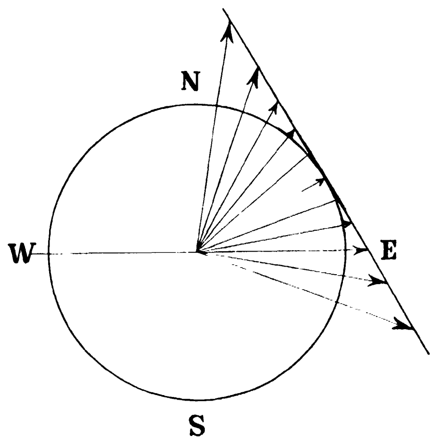


FIG. 58.—Principle involved in the construction of a great-circle chart.

The great-circle track between London and New York is shown transferred from the great circle to the Mercator chart in Figs. 60 and 61.

Problem: What are the Mercator track and distance from New York to Bermuda? From data supplied by the air-speed and fuel-consumption graphs shown in Figs. 47 and 49 (pages 50 and 51) and the following flight forecast (Fig. 62) work out the New York–Bermuda flight analysis. Select the most economical flight altitude, and complete the flight plan (Fig. 63).

Choice of Flight Altitude.—The choice of flight altitude is always made by the captain. The navigator should submit the flight analysis, predicted possible fuel consumptions, and the *flight forecast* to him for study. After he has selected a flight altitude, the flight plan itself is completed by the navigator. Several factors enter into the choice of flight altitude.

Terrain Considerations.—If the captain is familiar with the route, he will know at once whether or not the trip can be made at a low altitude.

If a new route is being flown or if the route extends over land areas, it is well for both navigator and captain to review the charts in order to

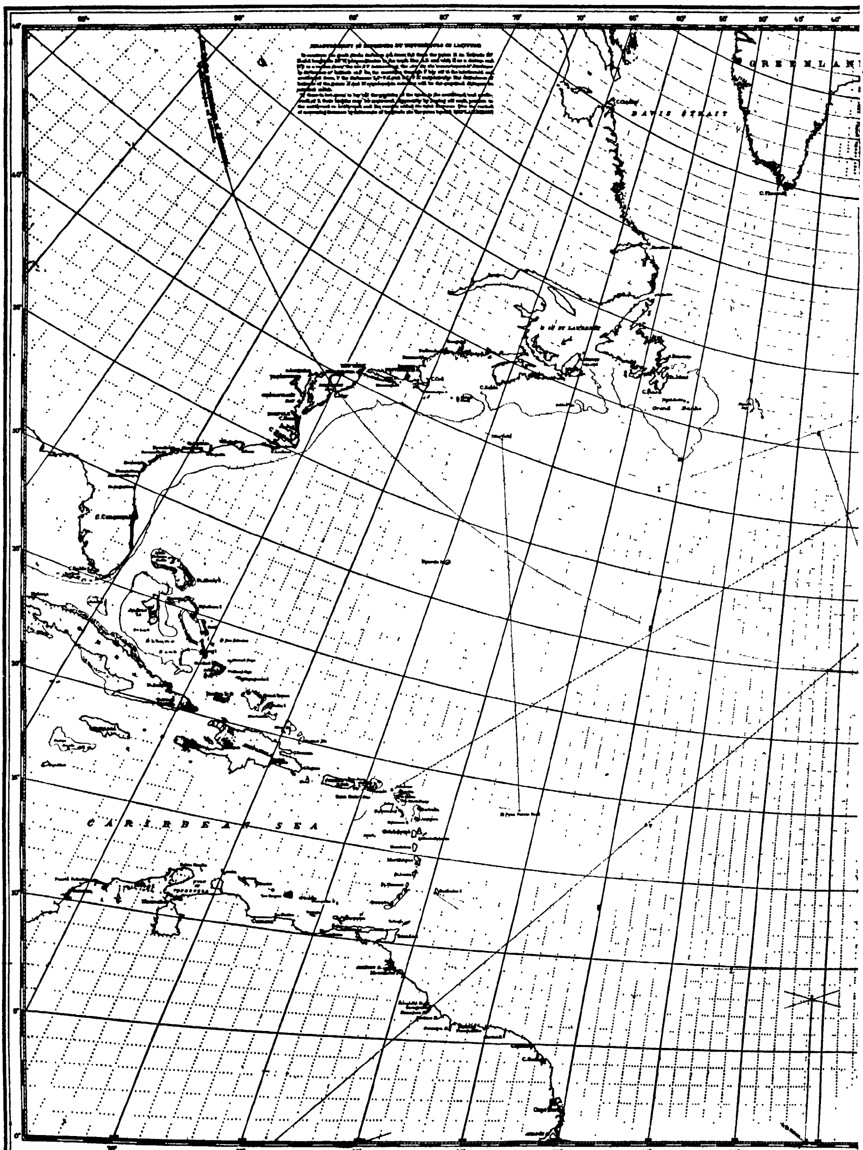
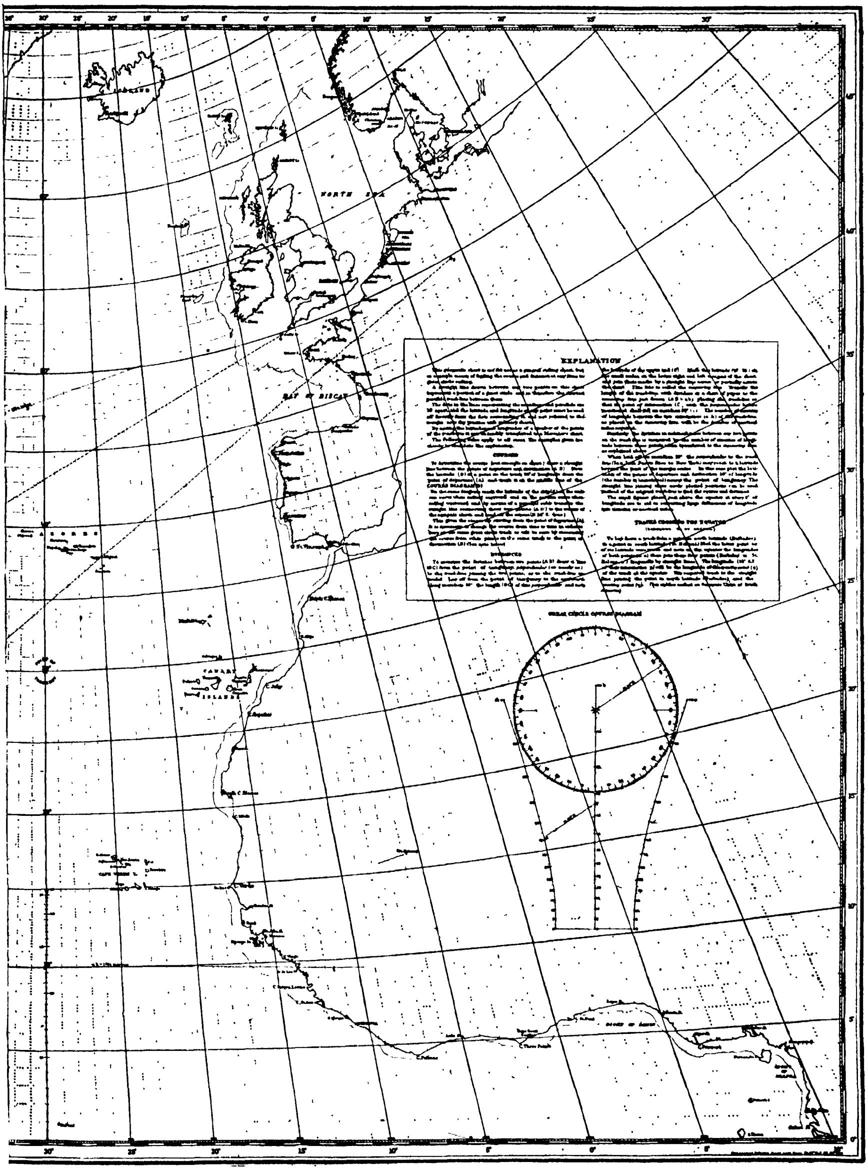


FIG. 59.—Small-scale reproduction

refamiliarize themselves with heights of terrain. Several methods of indicating these heights are employed.

Color tints ranging from green to dark brown are used on the United States aeronautical charts. These tints are inclusive in nature; *i.e.*,



of a great-circle chart.

green covers elevations up to 1,000 ft., pale brown is used to denote an area in which the altitude of the terrain varies between 2,000 and 3,000

ft., and medium brown includes elevations between 5,000 and 7,000 ft. Figure 64 is a black-and-white reproduction of a portion of an aeronautical chart.

Occasionally, mountains will be found within a colored area that exceed in height the altitudes included by the color tint. The highest

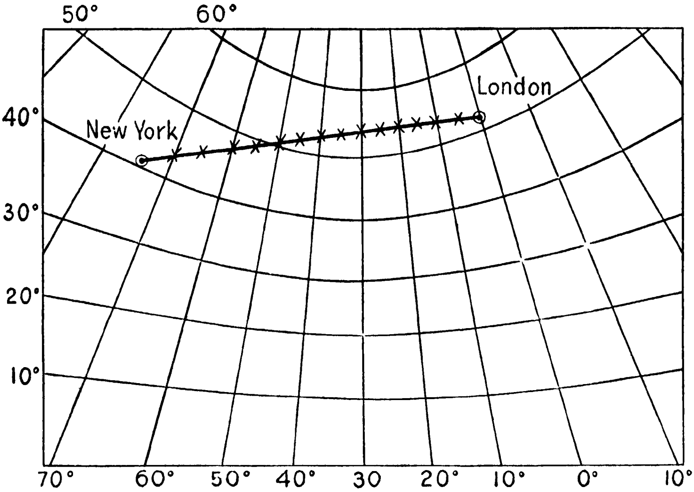


FIG. 60.—New York—London track on a great-circle chart.

elevation of a mountain is customarily shown beside a small black dot representing its peak. Such indications are known as **spot heights.**

Contour.—On the aeronautical charts thin brown lines, known as **contour lines,** connect points of equal elevation. The vertical interval between these lines is usually 1,000 ft., *i.e.*, the lines join points at 1,000,

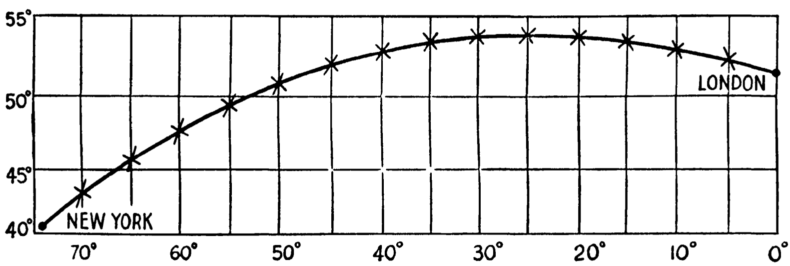


FIG. 61.—Track in Fig. 60 transferred to a Mercator chart.

2,000, 3,000, 4,000, and 5,000 ft. If these lines are broken, they must be considered approximate only. It is not safe to travel cross country at an altitude slightly above the charted contour. The 4,000-ft. contour line, for example, joins points 4,000 ft. above sea level, but within the countour the terrain may reach up to 4,999 ft. without justifying the

existence of the 5,000-ft. contour. Furthermore, trees may extend up another 150 ft.; thus, even if a plane were to fly at 5,000 ft. above the 4,000-ft. contour, it might crash.

TRANS-OCEAN AIR, INC.

WEATHER FORECAST NO. ______

BASED ON MAP *0600 GCT* FILED *0800 GCT*

PLANE *12345* PLACE *New York*

DEPT. TIME *1000 GCT* FROM *NY* TO *BDA* DATE *10-10-43*

ZONE ENDING	STATE WEATHER	AMT TYP BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP. BASE UPPER CLOUD	FREEZING LEVEL	WINDS 1000 FT.	5000 FT	7000 FT.	12000 FT
200	CLOUDY	3/10 Cu 2500'	3000'	6/10 Ci 25,000'	4000'	340-25	330-30	320-45	
400	MDT. CONT. RAIN	10/10 Nbs 1500'	20,000'	1/10 Ci 25,000'	12,000'	350-35	320-35	230-40	
670	PARTLY CLOUDY	3/10 Cu 3000'	3500'	NONE	16,000'	220-35	230-36	230-38	

TERMINALS	STATE WEATHER	AMT. TYP. BASE LOWER CLOUD	TOP LOWER CLOUD	AMT. TYP BASE UPPER CLOUD	FREEZING LEVEL	SURFACE WIND	VISIBILITY	REMARKS	
NORTH BEACH	CLOUDY	4/10 Cu 2500'	3000'	3/10 Ci 21,000'	3,000'	340-25 Kts	16 miles	GUSTY SURFACE WIND	
BERMUDA	PARTLY CLOUDY	3/10 Cu 2500'	3000'	NIL	16,000'	220-20 Kts	10 miles		
BALTIMORE	CLOUDY	NIL	–	7/10 As 10,000'	8,000	020-24 Kts.	15 miles	GUSTY SURFACE WIND	

REMARKS:

Moderate slow moving cold front 400 miles out, mdt. to heavy continuous rain to westward of front with 10/10 nimbo stratus clouds, base 400 ft, tops 20,000 ft. Mdt. turbc., with strong shifting winds and rapid clearing weather as plane passes through front enroute to Bermuda from New York

METEOROLOGIST *Harol*

FIG. 62.—New York–Bermuda flight forecast.

NOTE: The color system used in this country is not necessarily the same as that used in other countries, nor is the system of stating heights in feet employed by countries using the metric system. The legend at the bottom of the chart should always be studied in order to ascertain the system used.

Terrain Heights—Ocean Charts.—The manner in which terrain heights are indicated on Mercator ocean charts is shown in Figs. 65 and

PLANE________ **TRANS-OCEAN AIR, INC.** DATE________

FLIGHT NO.________ **FLIGHT ANALYSIS** DEPT.________

BASED ON FORECAST________

1,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
		TOTALS				

4,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
		TOTALS				

10,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
		TOTALS				

FLIGHT PLAN

ALTITUDE

END OF ZONE	G.S.	TIME THRU ZONE	ACCUMULATIVE TIME	ACCUMULATIVE FUEL	GAS ABOARD
		TOTALS			

Gas Reserve________

Gas weight per gallon:________

Alternate:________ Time to point of no return________ (allowing ___ reserve)

Capt. Signature________ Nav. Signature________

Fig. 63.—New York–Bermuda flight analysis and flight plan.

66. Note that the steepness of a mountain can be estimated by the relative closeness of the contour lines. Color tints are rarely used on ocean charts.

Radius of Action from a Fixed Base.—If a plane flies in no wind, it may, at least theoretically, proceed toward its destination until half the

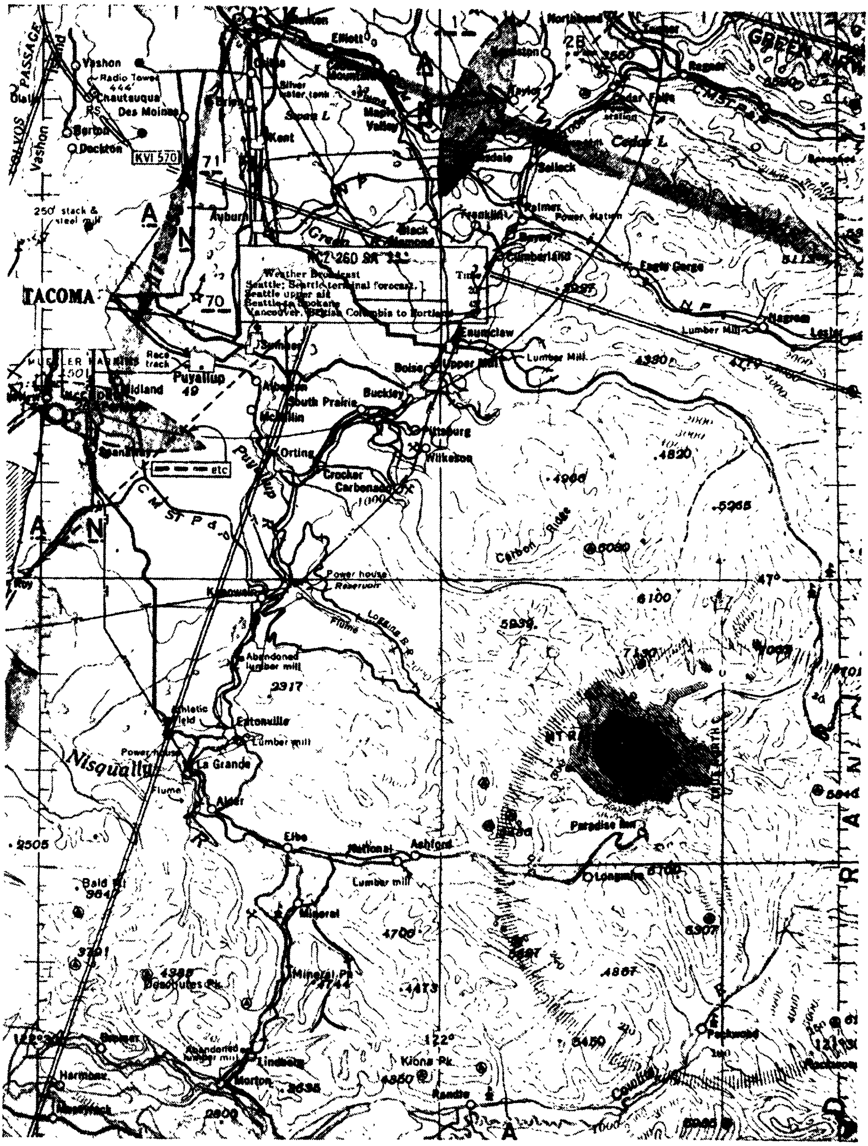


FIG. 64.—Aeronautical chart. (Elevation tints not shown.)

available fuel is consumed and, if necessary, return to its base. If a plane flies outbound with a tail wind, it must overcome a head wind if forced to return and under this condition cannot turn back even though

half the total gas supply remain intact. For this reason, the navigator should determine before take-off just how far out the plane may proceed and still get back to the starting point should it become necessary to do so.

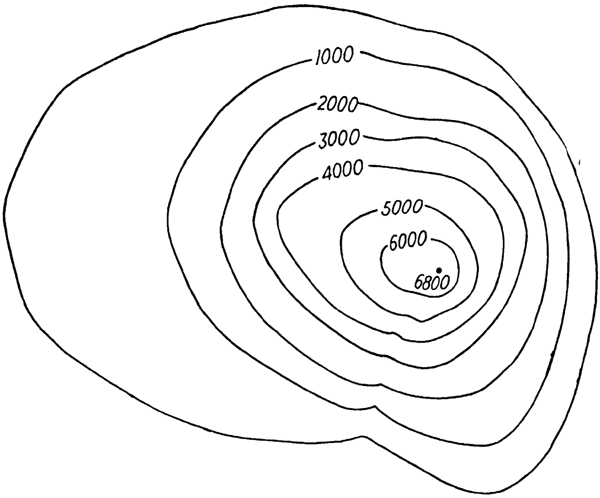


FIG. 65.—Contour lines.

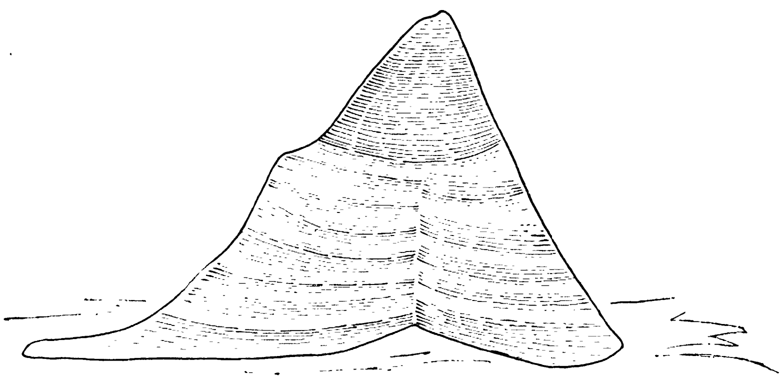


FIG. 66.—Island shown by the contour lines in Fig. 65.

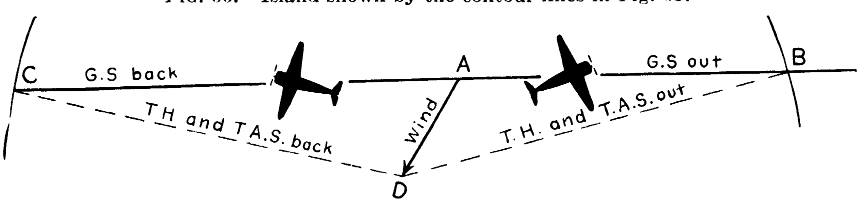


FIG. 67.—Determining ground speed from and to a fixed base.

Either the distance out along the track or the time to the so-called "point of no return" may be determined. In either case, the ground speed out and the ground speed back must be known in advance.

A graphical analysis of the method of determining ground speed out and back is shown in Fig. 67. The diagram itself does not furnish information as to how *far* the plane may proceed; it supplies only the ground speed out and the ground speed back. These are represented by lines AB and AC. The time out to the point of no return must be computed by means of the following formula:

$$t_1 = \frac{Tr_2}{r_1 + r_2}$$

The derivation of this formula is given below:

where T = total allowable flight time (leaving a reasonable reserve gas supply).

t_1 = time out to point of no return.

t_2 = time back from point of no return.

r_1 = rate of leaving A for B (ground speed out).

r_2 = rate of returning to A (ground speed back).

R = radius of action (distance to point of no return).

$$T = t_1 + t_2 \qquad\qquad T = \frac{R(r_2 + r_1)}{r_1 \times r_2}$$

$$t_1 = \frac{R}{r_1} \qquad \text{but} \qquad t_1 = \frac{R}{r_1}$$

$$t_2 = \frac{R}{r_2} \qquad \therefore \qquad T = \frac{t_1(r_2 + r_1)}{r_2}$$

$$T = \frac{R}{r_1} + \frac{R}{r_2} \qquad\qquad Tr_2 = t_1(r_2 + r_1)$$

$$T = \frac{Rr_2 + Rr_1}{r_1 \times r_2} \qquad\qquad t_1 = \frac{Tr_2}{r_1 + r_2}$$

Ground speed out along the track is already available in the flight plan, and ground speed back may be determined graphically as just shown by the use of the reciprocal track, *i.e.*, a track 180° opposite to the outbound track. It is more convenient, however, and usually sufficiently accurate to determine the ground speed back by means of the wind component. When the ground speed out is 10 m.p.h. greater than the true air speed, the wind component is +10, and it may be assumed without serious error that the ground speed back will be 10 miles less than the true air speed.

Problem: The true air speed is 150 m.p.h. The ground speed out is 175 m.p.h. A 7-hr. fuel supply, exclusive of reserve, is available for the flight.

Required: The flight time to the point of no return.

Procedure: The outbound wind component is +25. The return component may be assumed to be −25, and the ground speed back will be 125 m.p.h. Substituting these values in the point-of-no-return formula results in the following:

$$t_1 = \frac{7 \times 125}{175 + 125} = 2.91 \text{ hr.}$$

NOTE: The average ground speed out is taken from the flight analysis, but it is not taken for the entire trip distance. If the plane turns back, it will presumably turn back from a point not more than halfway to the destination. For this reason, the average ground speed to the halfway point is usually taken as the average ground speed out, and the resulting component is used to determine the ground speed back. Notice in the above problem that, although the flight was to be of 7 hr. duration, the plane could not get back without using some of its reserve if it proceeded more than 2.91 hr. Do not base the time to the point of no return on the total fuel supply. *Always exclude the reserve.*

Minimum reserves are set forth in company regulations. The total fuel carried, however, is rarely exactly equal to the sum of the required fuel plus reserve. The minimum fuel load is determined by means of the flight analysis and reserve regulations. In practice, the total fuel load may exceed this amount, depending on available pay load. That is, there will be a pause after the flight analysis has been completed until the pay load is definitely established and a report comes back from the loading officer as to exactly how much more than the minimum fuel it was possible to put aboard the plane. Since the radius of action is based on the total loaded fuel less minimum reserve, it is necessary to enter the fuel graph with the total *loaded* fuel quantity in order to determine the precise endurance of the plane. From this endurance figure, expressed in hours, minimum reserve must be subtracted and the result used in the point-of-no-return formula.

Example: A flight analysis calls for 7,300 lb. of fuel for a 6-hr. flight. The minimum reserve for this route is 3 hr.; 12,500 lb. of fuel is loaded. The true air speed is 142 m.p.h., and the ground speed out is 162 m.p.h.

Required: The time to the point of no return.

Procedure: The 12,500 lb. will enable the plane to fly 10.7 hr. (see the fuel graph, Fig. 49). A 3-hr. reserve must be maintained.

$$10.7 \text{ hr.} - 3 \text{ hr.} = 7.7 \text{ hr. allowable fuel}$$

The ground speed out is 162; the ground speed back is 122.

$$t_1 = \frac{7.7 \times 122}{162 + 122} = 3.31 \text{ hr.}$$

PROBLEMS

1. The amount of gas loaded on the last New York–Bermuda flight plan was 12,500 lb. Calculate the time out to the point of no return. Could the plane have made the entire round-trip flight without using the 3-hr. reserve?

2. From the flight plan of Fig. 68 solve for t_1. The air speed is 125 m.p.h.

Flight Control.—In the nature of things a good reserve does not guarantee a through flight, even though it provides a liberal safety margin

FLIGHT PLAN

ALTITUDE 1,000 feet

END OF ZONE	G.S.	TIME THRU ZONE	ACCUMULATIVE TIME	ACCUMULATIVE FUEL	GAS ABOARD -17,200
250	139	1.80 hours	1.80	1850	15,350
200	105	1.91 "	3.71	3800	13,400
450	115	3.92 "	7.63	7650	9,550
400	125	3.20 "	10.83	10900	6,300
425	131	3.24 "	14.07	13950	3,250
1725	TOTALS		14.07	13950	

Gas Reserve ____ 3250 pounds ____

Gas weight per gallon: ____ 5.75 ____

Alternate: ________ Time to point of no return (allowing 3hr reserve) ________

Capt. Signature ________ Nav. Signature ________

Fig. 68.—Example of a flight plan.

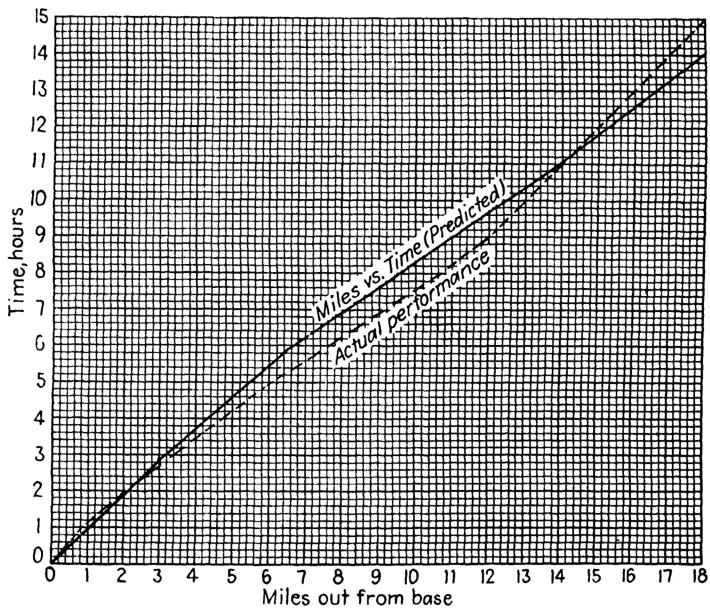


Fig. 69a.—Flight control: miles vs. time.

against unexpected head winds. It is the responsibility of the captain or his first officer to watch both mileage and fuel-consumption reports with a view to turning back when and if the fuel consumption per mile shows a positive and continued unfavorable trend.

PLANE ______ **TRANS-OCEAN AIR, INC.** DATE ______

FLIGHT NO. ______ **FLIGHT ANALYSIS** DEPT. ______

BASED ON FORECAST ______

1,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
300	070	E 22	126	105	2.86	3000
350	073	N29	126	114	3.07	3000
300	075	SW22	127	146	2.06	2000
400	080	W20	127	147	2.72	2700
450	085	NW14	128	136	3.31	3200
1800	TOTALS				14.02	

4,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

10,000 feet

ZONE DIST.	TRACK	WIND	A.S.	G.S.	TIME THRU ZONE	GAS REQUIREMENT
	TOTALS					

FLIGHT PLAN

A ALTITUDE B C

END OF ZONE	G.S.	TIME THRU ZONE	ACCUMULATIVE TIME	ACCUMULATIVE FUEL	GAS ABOARD 17700
300	105	2.86	2.86	3000	14700
650	114	3.07	5.93	6000	11700
950	146	2.06	7.99	8000	9700
1350	147	2.72	10.71	10700	7000
1800	136	3.31	14.02	13900	3800
	TOTALS		14.02	13900	

Gas Reserve 3800

Gas weight per gallon: 6.00 lbs.

Alternate: Bridgeport Time to point of no return ______ (allowing ___ reserve)

Capt. Signature ______ Nav. Signature ______

FIG. 69*b*.—Sample flight analysis and flight plan.

Miles vs. Time.—Once the flight is under way, the predicted performance is plotted on a graph in order that any unfavorable trend in the actual performance may be plotted and detected when compared with it.

The heavy solid line in Fig. 69*a* shows graphically just how much distance should be made good at any time after departure. The data on which this line is based are obtained from columns *A* and *B* in the accompanying flight plan (Fig. 69*b*). The dotted line represents the actual miles made good at various times out from the base. This information is ordinarily supplied by the navigator every hour on the hour. During the first hour a distance of only 85 miles was made good, and the dotted line shows this unfavorable trend by climbing above the solid line. By the end of the second hour, 200 miles had been made good; the dotted line shows the improvement by sloping back toward the solid

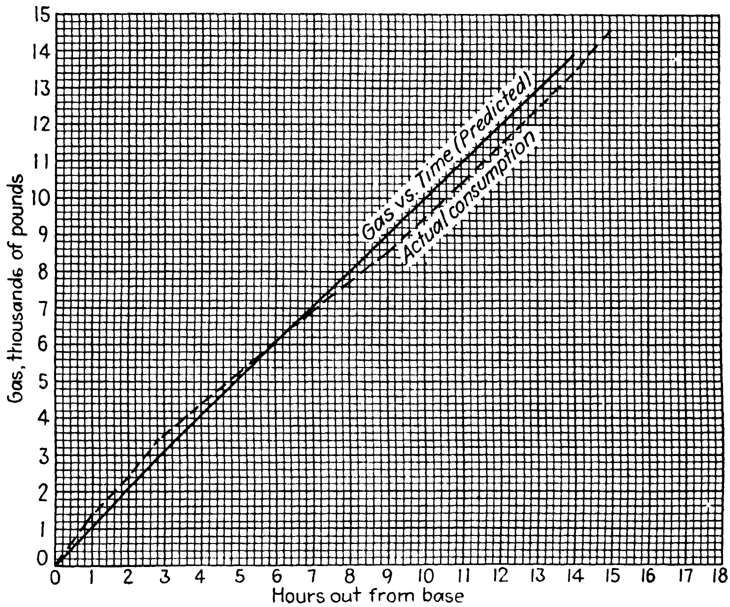


FIG. 70.—Flight control: gas vs. time.

line. At the end of 8 hr., 1,070 miles had been made good whereas the predicted 8-hr. mileage was 950 miles. The plane is well ahead of schedule.

From this time on the ground speed dropped below that predicted for the flight; although the slope of the dotted line shows this as a definite unfavorable trend, the plane did not drop behind schedule until after the fourteenth hour. From then on the plane continued to drop behind schedule and finally arrived 1 hr. late.

Gas vs. Time.—The predicted gas consumption is plotted in a similar manner. The solid line representing predicted consumption is based on data contained in columns *B* and *C* (Fig. 69*b*). Actual consumption

reported hourly in flight by the engineer is shown by the dotted line. The actual consumption is higher than it should have been during the first few hours; the predicted and actual consumptions are identical after 6 hr., and the actual consumption is less than that predicted from then to the end of the flight.

Miles vs. Gas.—The data for the predicted miles vs. gas curve are taken from columns *A* and *C* of the flight plan (Fig. 69*b*). Of the three curves, miles vs. time, gas vs. time, and miles vs. gas, this shows best whether the over-all performance is good or bad. Ground speed may be

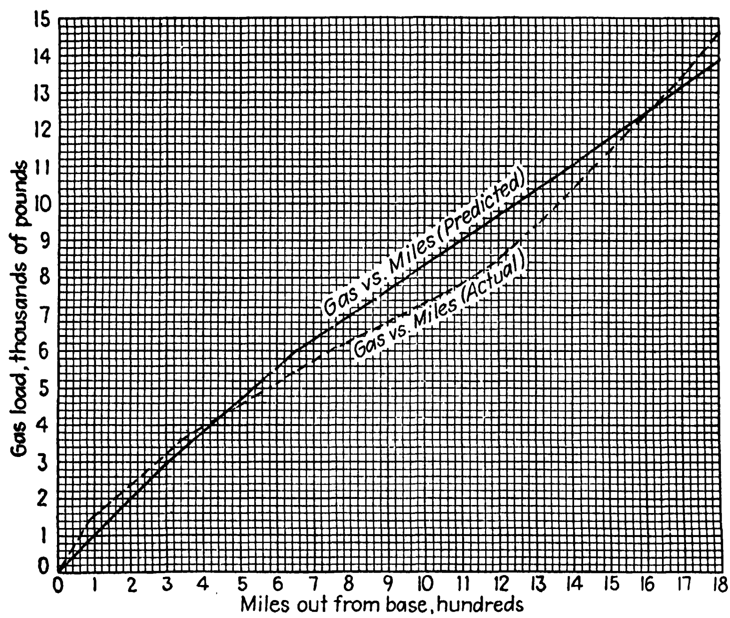


FIG. 71.—Flight control: gas vs. miles.

better or worse than that predicted for the flight; the fuel consumption may be higher or lower than that anticipated. This curve shows whether or not the fuel consumption per mile is greater or less than it should be. The ground speed may be sufficiently high to overcome less than expected engine efficiency, and the engine efficiency may on occasion offset unexpectedly low ground speeds. This is the curve that shows whether the net performance of the plane is satisfactory.

In the beginning of the flight (see Figs. 69*a* and 70) the ground speed was less than expected and the fuel consumption was higher than normal. Both dotted lines rose above the predicted performance lines. This is reflected in Fig. 71 by a pronounced unfavorable over-all performance.

At the end of the eighth hour, however, the plane had made 120 miles more distance than that predicted, and the gas consumption also was somewhat better than anticipated. This, too, is shown in the miles vs. gas graph (Fig. 71), in which the over-all performance, represented by the dotted line, shows the flight proceeding satisfactorily. After the eleventh hour the ground speed dropped considerably, but the gas consumption remained sufficiently below that predicted for the flight so that not until the plane was within 160 miles of its destination did it actually fall behind over-all scheduled performance.

Performance to Dry Tanks.—A discussion of dry-tank performance may at first seem academic, since no plane is dispatched with the expectation that it will consume all its gas in reaching its destination or that if forced to return it will arrive with empty tanks. Nevertheless, dry-tank performance does enter into the navigator's work.

Dry-tank performance data form a basis for a more equitable calculation of reserve than any other method. A 6-hr. reserve is an impressive one to have aboard at the mid-point of a long route. If the plane is within 100 miles of its destination, a 6-hr. reserve, amounting as it does to thousands of pounds, is altogether excessive. If a plane requires 600 gal. of gas to reach its destination, perhaps 40 per cent of this amount would be a reasonable reserve. That is, the reserve would in this way be made more or less proportionate to the flight distance involved.

Nevertheless, a pure percentage reserve is not in itself satisfactory. A 240-gal. reserve may be considered adequate for a flight requiring 600 gal. If, however, only 10 gal. is required to reach the destination, 40 per cent, or 4 gal., is not an impressive reserve. This inadequacy becomes all the more apparent when it is remembered that the plane may have to wait its turn to land or approach under instrument conditions that could not be foreseen when the reserve was calculated.

A combination of both fixed and percentage reserves, therefore, has more merit than either system by itself. It may be assumed, for example, that 200 gal. (roughly, 1,200 lb.) is satisfactory as a fixed reserve for unexpected maneuvering at the destination and that 20 or 30 per cent or some other arbitrary percentage reserve is sufficient to give security against unexpected weather conditions. Before this reserve can be determined, it first becomes necessary to calculate the minimum amount of gas required to reach the destination from various points along the route.

Flight Ahead to Dry Tanks.—Inspection of the flight plan (Fig. 69*b*) shows that 3.31 hr. is required to negotiate the last zone of 450 miles. Fuel sufficient for 3.31 hr. *must* therefore be aboard when the plane arrives at the beginning of the last zone. Fuel for 18 hr. was placed aboard at the commencement of the flight; not more than 14.69 hr. worth

of fuel can therefore have been burned by this time. Fuel for 14.69 hr. is equal to 14,500 lb. gas (see Fig. 49, page 51).

To negotiate the last two zones takes 6.03 hr. Since 18 hr. worth of fuel was put aboard, not more than 11.97 hr. worth of fuel can have been used on arriving within two zones of the destination. Inspection of the fuel graph (Fig. 49) shows that this is equal to 12,000 lb. Finally, 8.09 hr. will be used in negotiating the last three zones, which means

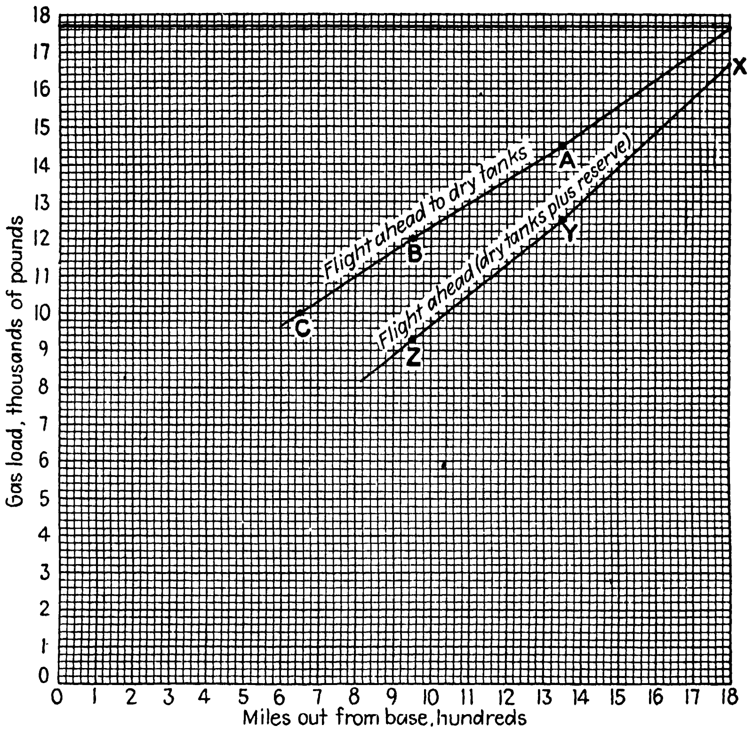


FIG. 72.—Flight control: flight ahead to dry tanks.

that not over 10 hr. worth of fuel can have been burned on arriving within three zones of the destination. Fuel for 10 hr. is equal to 10,000 lb.

These fuel values are represented by points A, B, and C on the graph in Fig. 72, and the line connecting them shows how much fuel can have been burned at any point and still allow the plane to get in with dry tanks. The vertical distance above this line represents the fuel required to proceed.

The reserve requirement is based on the quantity required to proceed to dry tanks. At point A, 3,200 lb. of fuel is required to proceed ahead to dry tanks. Thirty per cent of this amount, or 960 lb., may be con-

sidered sufficient to give security against head winds, and 1,000 lb. may be sufficient to allow for maneuvering at the end of the trip. This means that a 1,960-lb. reserve is satisfactory at point *A*. Since 3,200 lb. is the minimum and 1,960 lb. the reserve, a total of 5,160 lb. should be aboard the plane at point *A* to ensure safe operation. This establishes point *Y* on the graph.

At point *B*, 5,700 lb. is required to proceed ahead to dry tanks. Thirty per cent of this amount is 1,710 lb., which, when added to the

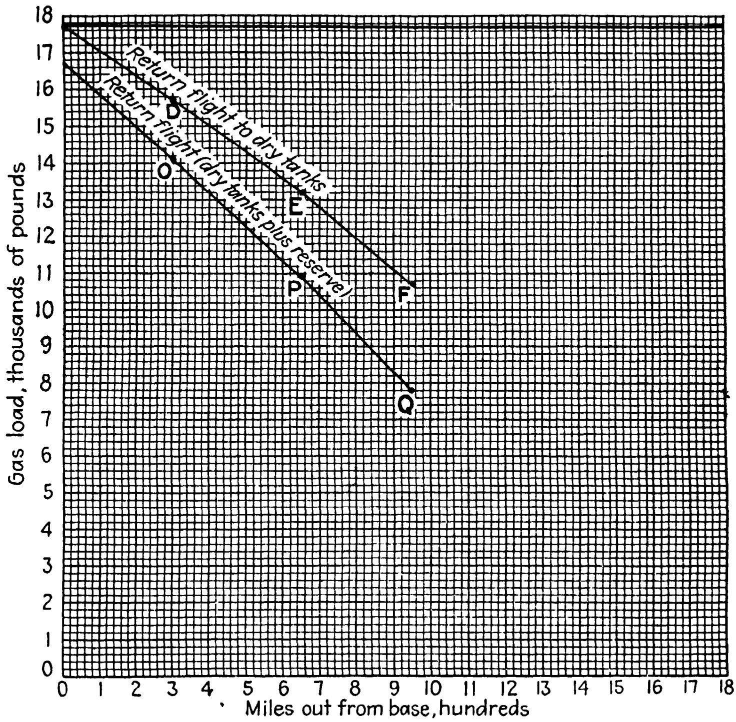


FIG. 73.—Flight control: return flight to dry tanks.

1,000-lb. fixed reserve, satisfies the reserve requirement for a point two zones distant from the destination. This means that a total of 8,410 lb. should be aboard and establishes the point *Z* on the graph. At the very end of the trip 1,000 lb. is required for maneuvering purposes; this establishes point *X*. By joining these points *X*, *Y*, and *Z*, a curve of minimum safe fuel requirements is established.

Return Flight to Dry Tanks.—What has already been said regarding flight ahead to dry tanks applies in principle to a return to dry tanks. It becomes necessary in this phase of the work to determine what ground

speeds will be made through each return zone. In this discussion, these will be determined by components. The true air speed in the first zone was 126 knots, and the ground speed was 105; the return ground speed through the first zone would therefore be about 147 knots. At this speed 2.04 hours would be required to return through what now becomes the last *return* zone. Fuel (17,700 lb.) representing 18 hr. total endurance, was loaded. For this reason, only 15.96 hr. worth of fuel can have been

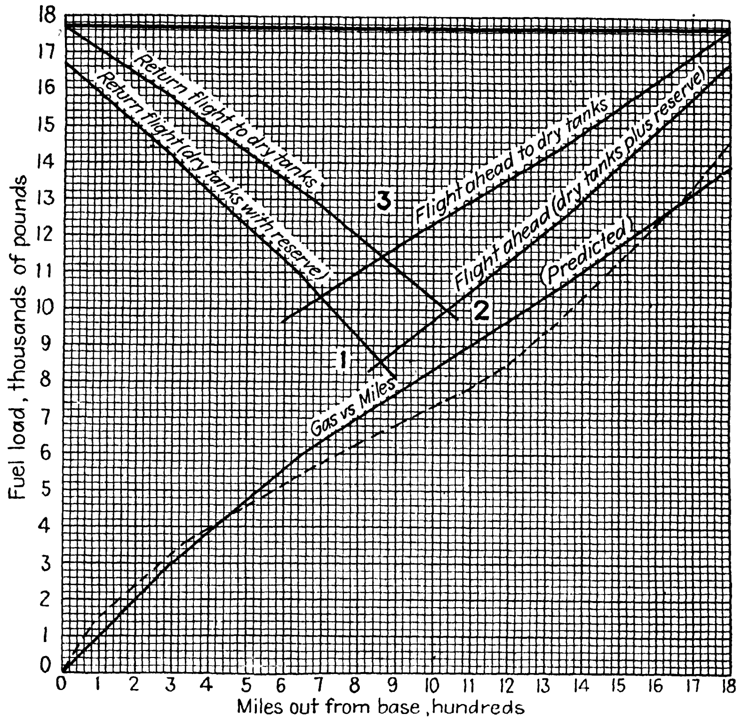


FIG. 74.—Flight control: the "Howgozit."

burned (on the outbound and return flights) up to a point 300 miles from the return base. A 15.96-hr. flight requires 15,700 lb. of gas; this and the 300-mile distance establish point *D* on Fig. 73.

By using the component system it can be shown that 4.58 hr. is required to negotiate the last two homeward-bound legs. This means that not more than 13.42 hr. worth of gas can have been burned by the time the plane reaches a point two zones from its base. A time of 13.42 hr. represents 13,200 lb. of gas, and the two zones are equal to 650 miles. This establishes point *E*.

In a similar manner, point F is established, and the line connecting points D, E, and F is a line of minimum requirements for a return to dry tanks. Again the vertical distance above this line shows the minimum dry-tank gas requirements. The actual return-flight *working* curve may be established by means of percentage and fixed reserves as in the flight ahead. This line is the line OPQ.

"Howgozit" Graphs.—The "howgozit" graph is shown in Fig. 74. It shows the dry-tank performance, dry-tank plus reserve performance, and the predicted gas vs. miles performance outbound, all of which were shown separately in Figs. 69*a* to 73. Notice that at the very beginning of the flight the actual consumption trend was such that had it continued it would have extended into the triangle representing minimum dry-tank fuel requirements.

If the curve had reached a point such as 1 in Fig. 74, the plane could have *returned* with a safe margin of fuel but it could not have *proceeded* ahead with a safe margin. At point 2 the plane could have proceeded ahead safely, but it could not have returned. At point 3, had the curve reached this point, the plane could not have reached either its destination or its base.

Summary.—What we have just discussed is the *method* by which the captain or his first officer is enabled to watch unfavorable trends in the over-all performance of his plane. The "howgozit" graph enables him to reach a quick decision as to whether the plane should turn back or proceed. In point of fact, dry-tank calculations are not based on full engine performance. In actual practice these curves are based on performance resulting from the loss of an engine; *i.e.*, with a four-engine craft they are based on three-engine air speeds and three-engine fuel consumption, and on a twin-motored plane they should be based on single-engine performance. The exact company details must be acquired when assigned to a specific company and plane.

In flight the over-all performance curve (gas vs. miles) is never allowed to extend into an area on the "howgozit" graph that would indicate that, if an engine failed, the plane could not go either ahead or back with a safe margin of fuel.

The "howgozit" has been discussed at this point because the data on which it is based, *i.e.*, three-engine ground speeds and consumptions, are determined by the navigator prior to take-off.

CHAPTER IV

FLIGHT INSTRUMENTS AND THEIR USE

Altimeters.—In working out the flight-time analyses with Chart 3060*b* (see pages 20 to 21) the student may have noticed the possibility of collision near airway intersections and large cities. Government regulation stipulates altitudes to be used on the airways to reduce this hazard. Aircraft flying along the same route in opposite directions are normally separated vertically by 1,000 ft.; at airway intersections, however, this clearance is reduced to 500 ft. Since maintenance of exact flight altitude in rough weather is difficult, this altitude separation may on occasion be unavoidably reduced. Then, too, since the altimeters on approaching planes may be less than perfect, erroneous indications may further reduce the vertical clearance. With these facts in mind, the need for a clear understanding of the limitations and usage of altimeters should at once be apparent.

Function of Altimeters.—The function of an altimeter (which is really a pressure gauge) is to show the altitude of the plane above some reference level. Altimeters utilize the principle that the amount of air bearing down on the earth decreases with altitude. At sea level, for example, the weight of this air produces a pressure of about 15 lb. per square inch; at 40,000 ft. the pressure amounts to approximately 3 lb. per square inch. Thus an approximate relationship between altitude and pressure is established that justifies the marking of the altimeter face in feet rather than in units of pressure.

Air-pressure Terminology.—In the discussion of altitude the term *pounds per square inch* is seldom used. It so happens that the mercury in a barometer tube rises about 30 in. in a vacuum under an air pressure of 15 lb. per square inch, and this has led to a system of stating pressures in terms of inches of mercury rather than in pounds per square inch. The U.S. Weather Bureau in July, 1939, discontinued the use of inches in its *sea-level pressure reports* and now uses the international **millibar unit.** Domestic air lines, however, in reporting *altimeter settings* still employ the term *inches of mercury.*

Pressure Drop.—Aircraft altimeters are constructed to show a certain increase of altitude for a certain standard decrease of pressure. If a plane's altimeter is set to read 0 at sea level under standard atmospheric conditions, it will show 1,000 ft. when the plane has climbed up through

enough air to bring about a 1.06 in. decrease in pressure. It will show 2,000 ft. when it has climbed up through enough more air to bring about a further decrease of 1.04 in. of air pressure. Additional values of standard pressure drop and the corresponding altimeter indications are set forth in Table I. When air temperature conditions are abnormal, the pressure drop does not correctly indicate the true height of the column of air through which the plane has climbed.

TABLE I.—STANDARD AIR PRESSURE DROP WITH INCREASE IN ALTITUDE

Altitude, feet	Standard atmospheric pressure, inches	Pressure drop, inches
−1,000 ft.	31.02	
		1.10
Sea level	29.92	
		1.06
+1,000	28.86	
		1.04
2,000	27.82	
		1.01
3,000	26.81	
		0.97
4,000	25.84	
		0.95
5,000	24.89	
		0.91
6,000	23.98	
		0.89
7,000	23.09	
		0.87
8,000	22.22	
		0.84
9,000	21.38	
		0.81
10,000	20.57	
		0.79
11,000	19.79	
		0.76
12,000	19.03	
		0.74
13,000	18.29	
		0.72
14,000	17.57	
		0.69
15,000	16.88	

Warm air weighs substantially less than cold air at the same pressure. If a plane climbs 1,000 ft. through warm air, a lesser pressure drop and altitude change is recorded than would have been the case had it climbed

1,000 ft. through cold, heavy air. That is, on a hot summer day when the air per cubic foot weighs less than normal, the altimeter on a plane that has climbed 1,000 ft. above sea level may show an altitude of but 900 ft. This is because the plane has not climbed up through enough of the hot, thin air to bring about the normal pressure drop.

On the other hand, on a cold winter day at the same airport *with the same sea-level pressure* the air is considerably heavier. Under these conditions, the altimeter shows 1,000 ft. *before the plane actually reaches that height* because the climb through the cold, heavy air brings about a

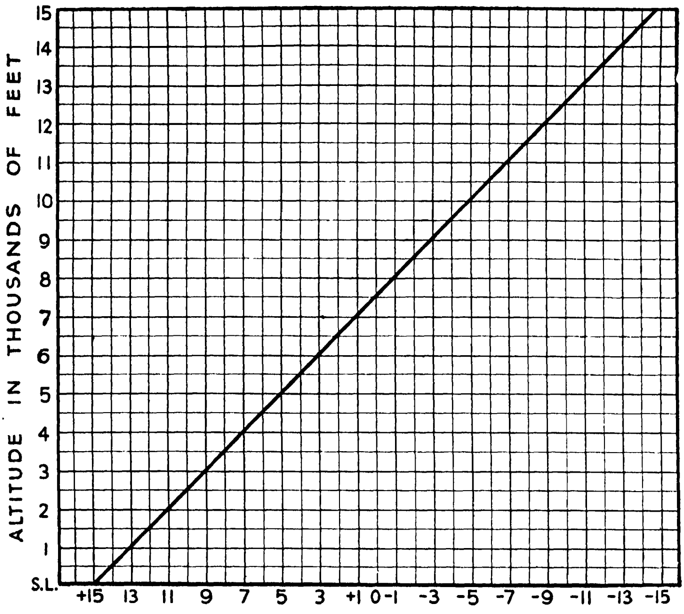


FIG. 75.—Standard centigrade temperatures at various altitudes.

premature decrease in pressure. It should always be remembered that *whenever the plane is flying in substandard temperatures the altimeter shows more than the actual altitude.*

Approximate Method of Correcting Indicated Altitude.—In flying under nonstandard temperature conditions, the altimeter indication may be corrected approximately according to the following rule of thumb. *Subtract* 2 per cent of the altimeter reading when the flight-altitude air temperature is 10°F. (5.5°C.) *colder* than standard. *Add* 2 per cent of the altimeter reading when the flight-altitude air temperature is 10°F. (5.5°C.) *warmer* than standard. In Fig. 75 standard temperatures are shown for various altitudes.

PROBLEMS

1. The altimeter reading is 7,000 ft. The air temperature is +53°F. (11.7°C.).

Required: The true altitude.

Procedure: Enter the graph of standard temperatures, and ascertain the standard temperature for 7,000 ft. (1°C.). Compare this with the *actual* temperature of 11.7°C. The difference is 10.7°, or approximately 11°C. Since a difference of 5.5°C. necessitates a correction of 2 per cent, an 11° difference necessitates a correction of 4 per cent. Four per cent of 7,000 is 280 ft. It is warmer than standard; so the plane is 280 ft. higher than the indicated 7,000-ft. altitude. *Ans.:* 7,280 ft. is the "true" altitude.

Work the following, and check your answers:

2. The altimeter reads 10,000 ft. The outside temperature is 10°F. (−12°C.).
Required: The true altitude. *Ans.:* 9,745 ft.

3. The altimeter reads 4,000 ft. The outside temperature is −4°F. (−20°C.):
Required: The true altitude. *Ans.:* 3,610 ft.

Absolute-temperature Method of Correcting Indicated Altitude.—The rule of thumb just described is a good general rule to keep in mind, but more accurate correction of indicated altitudes is possible.

Altimeters show correct altitude changes when functioning in standard-density air columns. If the air-column temperature is standard, the air column itself is of standard height. If the observed air-column temperature differs from standard, it is not of standard height.

The height of two air columns, in which the same pressure drop occurs, is proportional to their **absolute temperatures.** Absolute temperatures are reckoned from −459°F. (−273°C.) as base values. This presupposes that the air columns are under the same pressure. The following fraction is therefore used to express the relationship between the true height of an air column through which the plane has climbed and the altimeter's indication of that height:

$$\frac{273 \text{ plus or minus the air column's average temperature}}{273 \text{ plus or minus the air column's average } \textit{standard} \text{ temperature}}$$

The average (mean) standard air-column temperature is obtained by adding the standard temperature at the base of the column to the standard temperature at the top of the column and using the average.

Problem: A pilot takes off from sea level, where the temperature is 0°C., and climbs to an indicated 10,000-ft. altitude, where the temperature is −20°C.

Required: The correct altitude of the plane.

Procedure: The average temperature of the 10,000-ft. indicated column of air is −10°C. Inspection of the standard-temperature graph (Fig. 75) shows that the mean temperature should be +5°C. (+15°C. added to −5°C. is +10°C., the

average of which is +5°C.). Application of these values in the fraction results in the following:

$$\frac{273 - 10}{273 + 5} = \frac{263}{278}$$

This fraction expresses the relationship between the true height of the air column (and hence the aircraft) and the height of the aircraft as shown by the altimeter. The true altitude is obtained by multiplying the indicated altitude by this fraction:

$$\frac{263}{278} \times 10{,}000 = 9{,}460 \text{ ft.}$$

This is the correct approach to problems involving the determination of the true height of an air column through which a plane has climbed. Use of this method is somewhat limited by the fact that the mean temperature of an air column cannot be determined unless the temperature at its base is known. Even with exact information as to the temperature at the base, the calculated height of the air column may be somewhat in error. Warm air masses occasionally overlay cold air masses and bring about erroneous mean-temperature assumptions.

Obtaining True Altitude with Computer.—The speed with which an aircraft travels makes it imperative to ascertain its true altitude with the least possible delay. This work is usually performed with a computer such as that shown on the face of the slide rule described on page 38. The principle underlying the correction of altitudes by computer is the same as that just discussed under Absolute-temperature Method of Correcting Indicated Altitudes. In practice, however, this is not obvious, because the computer is arranged so as to supply the "true" altitude after a temperature and altitude setting has been made.

Correcting Indicated Altitude for Average Air-column Temperature.—As stated before, this method requires a knowledge of the ground temperature beneath the plane.

PROBLEMS

1. A pilot takes off from sea level with altimeter set to read 0 ft. The temperature is 0°C.; at 10,000-ft. indicated altitude the temperature is −20°C. (This problem has just been solved by means of graphs and absolute temperatures.)

Required: The correct altitude of the plane by computer.

The computer solution to this problem is shown graphically in Fig. 76. The average altitude is 5,000 ft., and the average temperature is −10°C. These values are shown set opposite each other on scales *C* and *D*. Opposite 10,000 ft. on scale *B* is read the correct altitude, 9,460 on scale *A*.

2. A plane takes off from sea level with altimeter set to read 0. The temperature is plus 5°C. At an indicated 5,000-ft. altitude the temperature is −10°C.

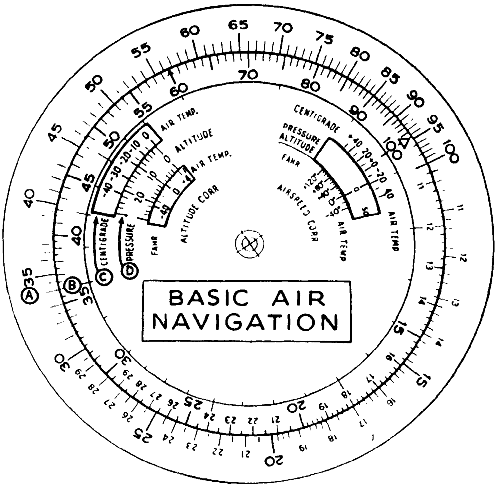


FIG. 76.—Computer solution of Prob. 1.

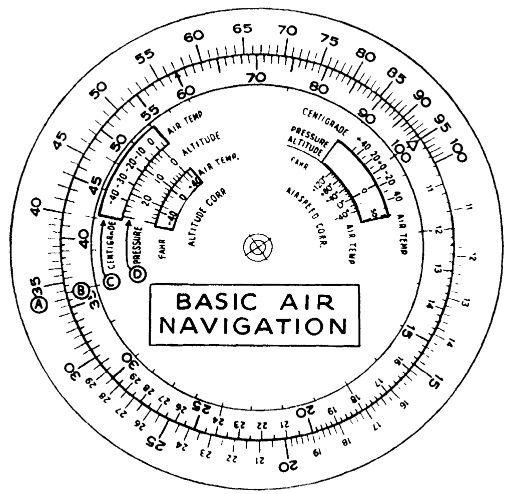


FIG. 77.—Computer solution of Prob. 2.

Required: The true altitude of the plane.

The computer solution to this problem is shown in Fig. 77. The average altitude (2,500 ft.) is shown set opposite the average known temperature, −2½°C. Opposite 5,000 ft. on scale *B* read the correct altitude, 4,770 on scale *A*.

3. From the data in Fig. 78, compute the true altitude of the plane.
4. From the data in Fig. 79, compute the true altitude of the plane.
5. From the data in Fig. 80, compute the true altitude of the plane.
6. From the data in Fig. 81, compute the true altitude of the plane.

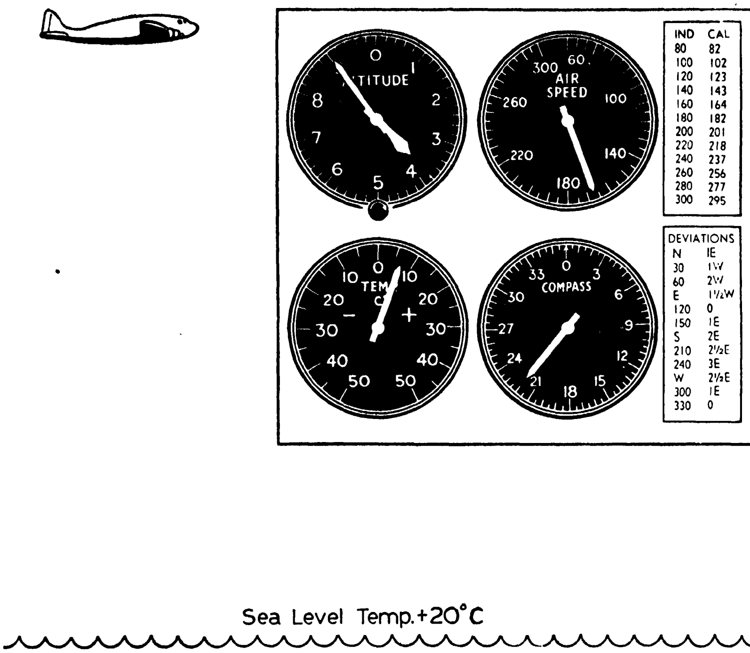


FIG. 78.—Problem in determining true altitude.

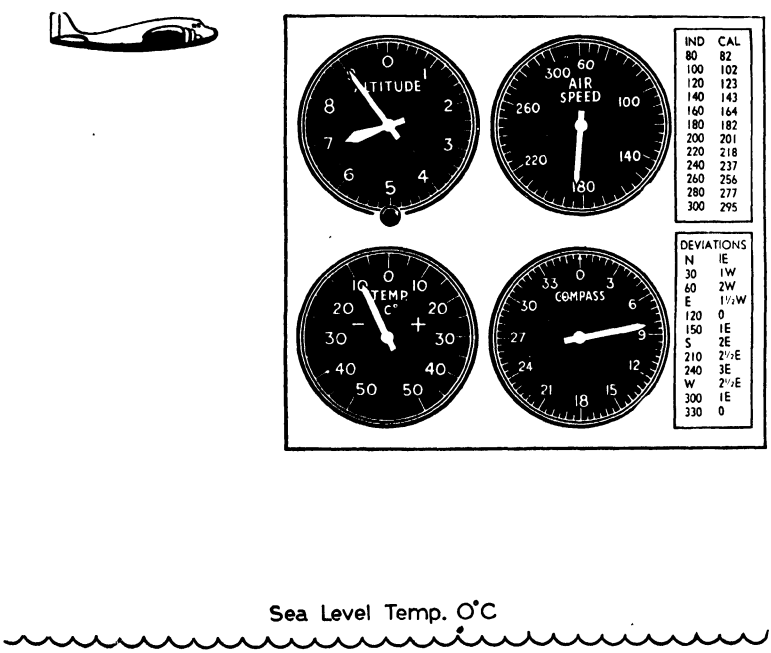


FIG. 79.—Problem in determining true altitude.

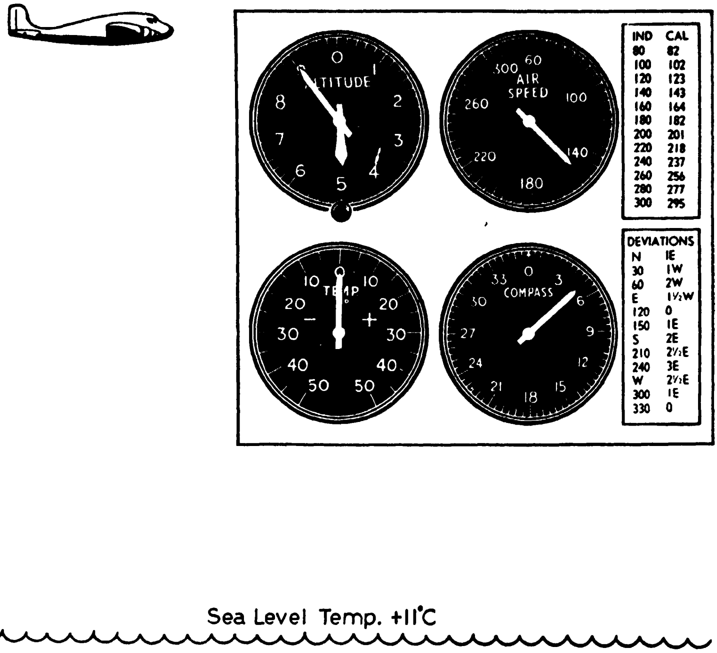


FIG. 80.—Problem in determining true altitude.

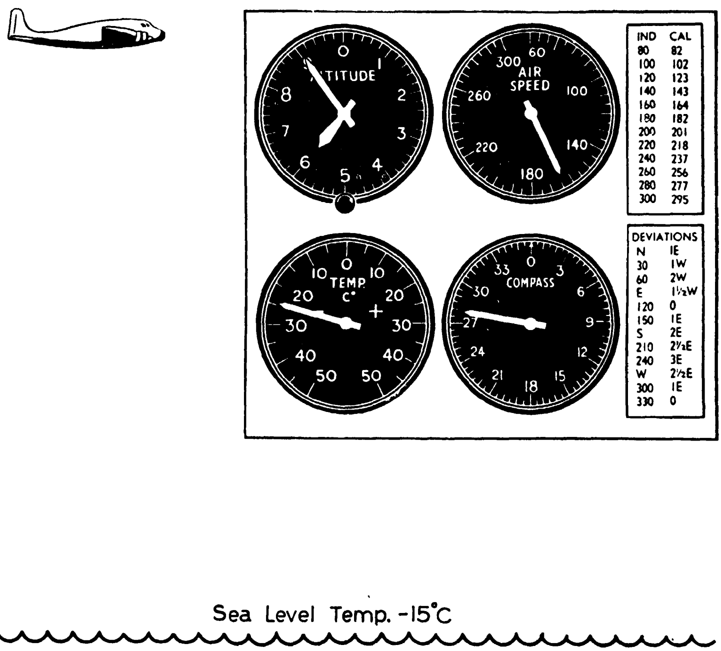


FIG. 81.—Problem in determining true altitude.

Determination of True Altitude above Airports.—Prior to take-off the altimeter is set to show the altitude of the field. Thereafter the *true altitude of the plane* is determined as follows: The mean temperature between airport and plane is determined. This is set opposite the mean altitude of the air column between airport and plane. The true altitude of the plane above the *airport* is read on scale *A* opposite the indicated height of the aircraft above the airport on scale *B*. That is, the height of the column of air above the airport through which the plane climbed is determined. This value is added to the altitude of the airport itself in order to obtain the true altitude of the plane above sea level.

PROBLEMS

1. A plane leaves a 4,000-ft. airport with altimeter set to read 4,000 ft. The temperature is 0°C. At 10,000 ft. indicated altitude the temperature is -20°C.

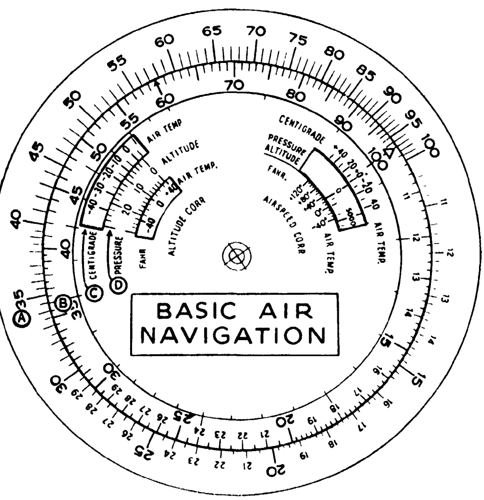


FIG. 82.—Computer solution of Prob. 1.

Required: What is the true height of the plane above the airport? What is the true altitude of the plane?

Procedure: The computer solution to this problem is shown in Fig. 82. The mean temperature between the plane and airport is -10°C. The mean altitude of the air column between the plane and airport is 4,000 plus 10,000 divided by 2, or 7,000 ft. Using scales *C* and *D*, set 7,000 ft. opposite -10°C. Opposite 6,000 on scale *B* (6,000 ft. is the indicated altitude above the field), read 5,750 on the outer scale *A*.

Ans.: The plane is 5,750 ft. above the airport. The plane is 9,750 ft. above sea level.

2. A plane takes off from a 2,000-ft. airport with altimeter set to read 2,000 ft. The temperature is +10°C. At 10,000-ft. indicated altitude the temperature is 0°C.

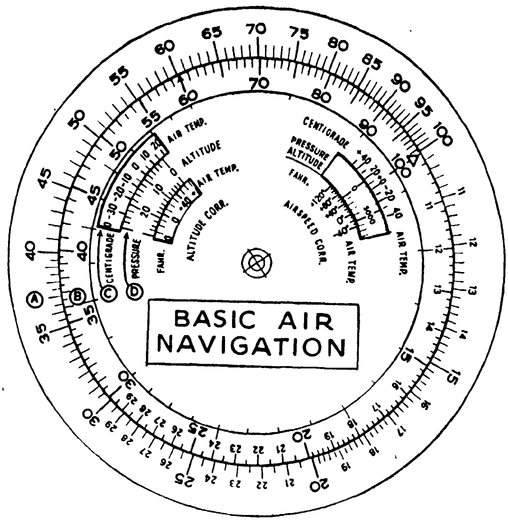


FIG. 83.—Computer solution of Prob. 2.

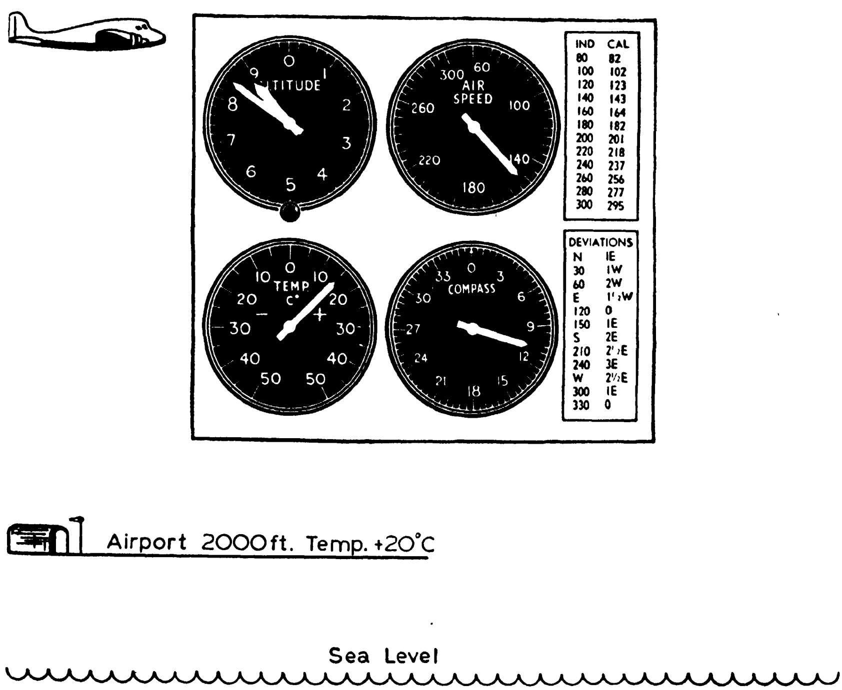


FIG. 84.—Problem in determining altitude above an airport.

Required: (*a*) The height of the plane above the airport. (*b*) The height of the plane above sea level.

Procedure: The computer solution is shown graphically in Fig. 83. The average temperature of this air column is +5°C., and its mean height is 6,000 ft. Using scale *C* and *D*, set 6,000 ft. opposite +5°C. Read the correct height of the column of air above the airport on scale *A* opposite 8,000 on the inner scale *B*.

Ans.: (*a*) The aircraft is 8,000 ft. above the airport. (*b*) The aircraft is 10,000 ft. above sea level.

3. From the data in Fig. 84 compute the altitude of the plane above sea level.

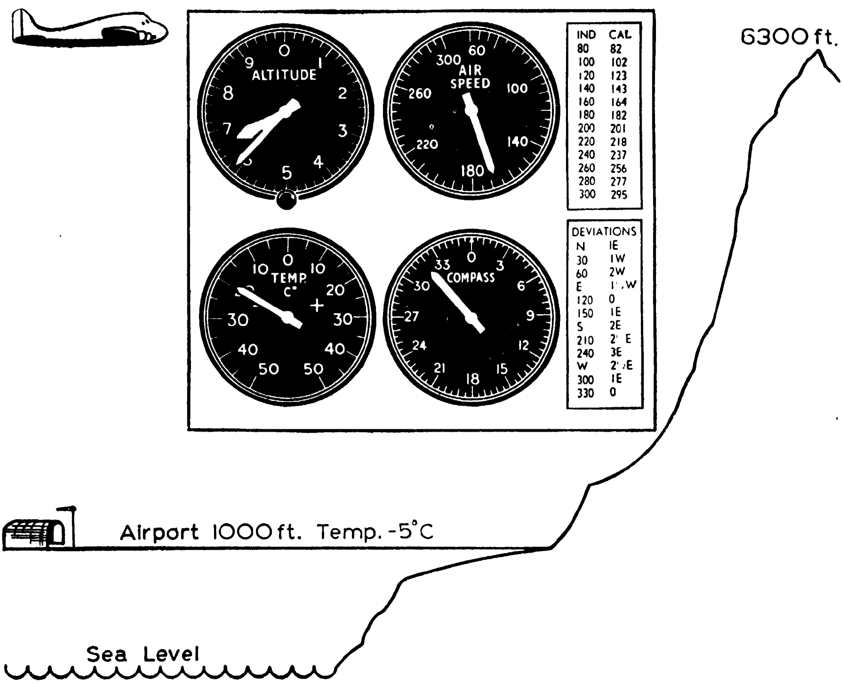


FIG. 85.—Problem in determining altitude above an airport.

4. From the data in Fig. 85, compute the altitude of the plane above sea level.
5. From the data in Fig. 86, compute the altiude of the plane above sea level.
6. From the data in Fig. 87, compute the altitude of the plane above sea level.

Correcting Indicated Altitude—Ground Temperature Unknown.—In flying over strange territory or the open sea the surface temperature is usually unknown. For this reason, even though the flight-altitude temperature is known, the mean temperature of the air column cannot be accurately determined. Under such conditions, the navigator assumes that standard flight temperature indicates the existence of a standard air column beneath the plane. He likewise assumes that nonstandard

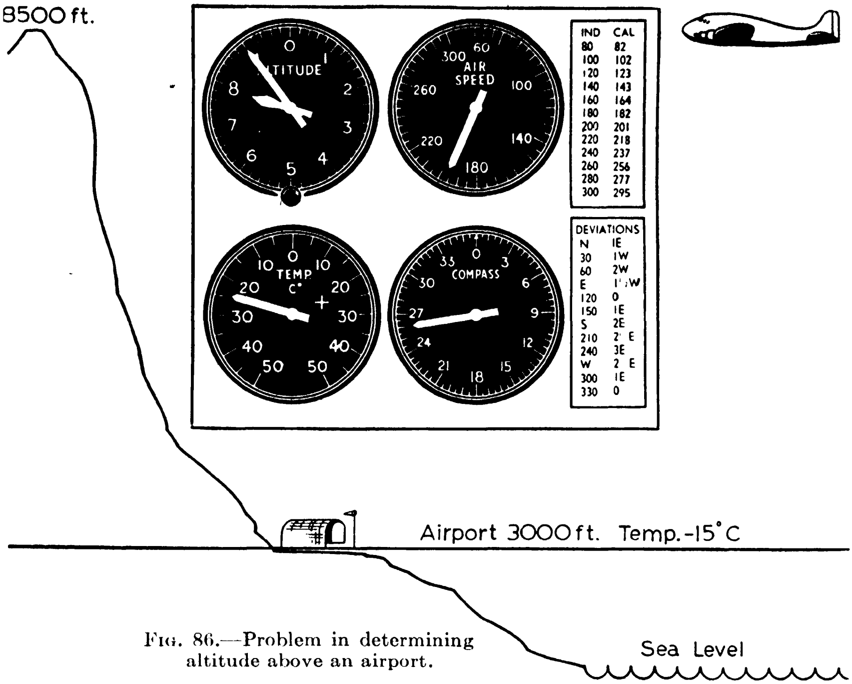


Fig. 86.—Problem in determining altitude above an airport.

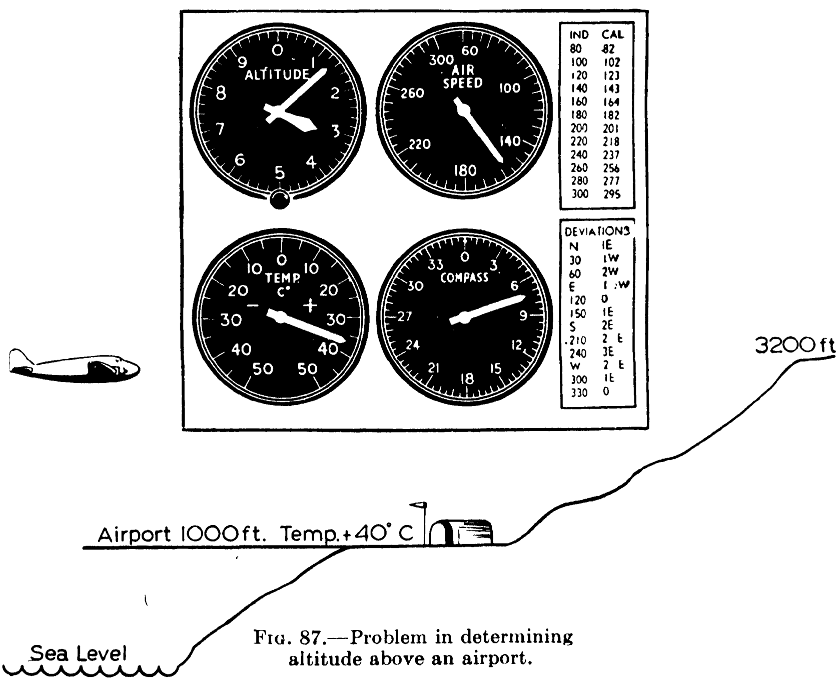


Fig. 87.—Problem in determining altitude above an airport.

flight-altitude temperature proves the existence of a nonstandard column of air beneath the plane.

The "true" altitude of the plane is obtained with the computer as follows: Using scale C and D the indicated flight altitude is set opposite

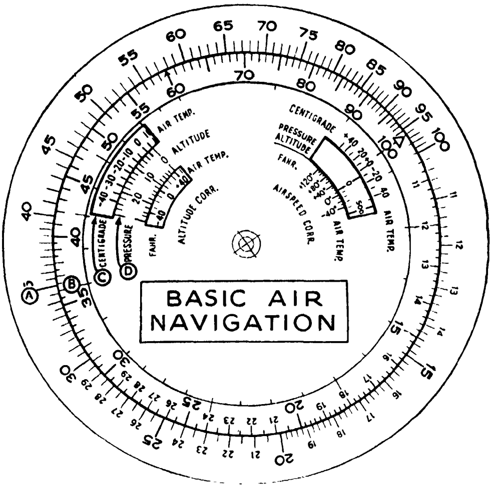


FIG. 88.—Computer solution of Prob. 1.

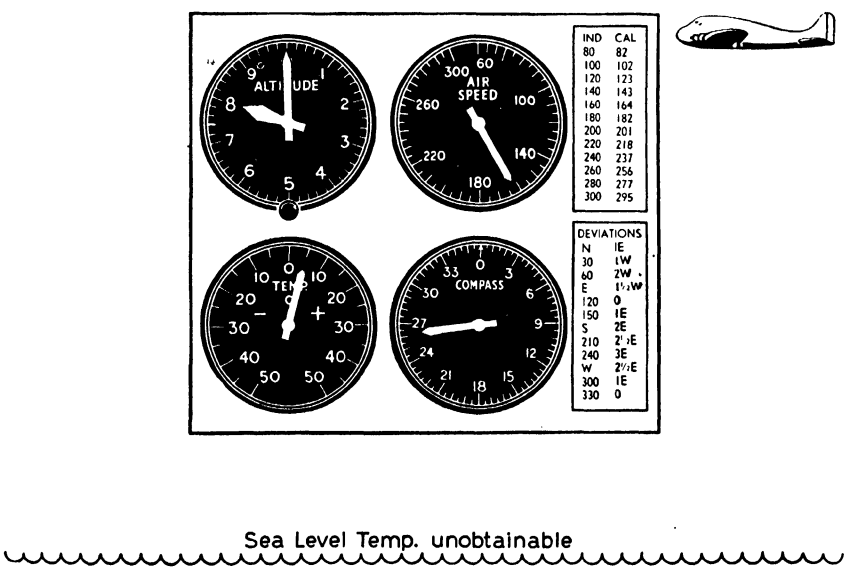


FIG. 89.—Problem in determining altitude.

the observed flight temperature. Using scale A and B, the true altitude is read on the outer scale opposite the indicated flight altitude on the inner scale.

PROBLEMS

1. A plane is in flight over the open sea at an indicated altitude of 8,000 ft. The temperature is $-10°C$.

Required: The true altitude of the plane.

Procedure: This problem is illustrated in Fig. 88. Set 8,000 ft. and $-10°C$. opposite each other on scales C and D. Opposite 8,000 ft. on scale B read the true altitude, 7,700 ft. on scale A.

2. From the navigator's instrument panel shown in Fig. 89, determine the altitude of the plane above sea level.

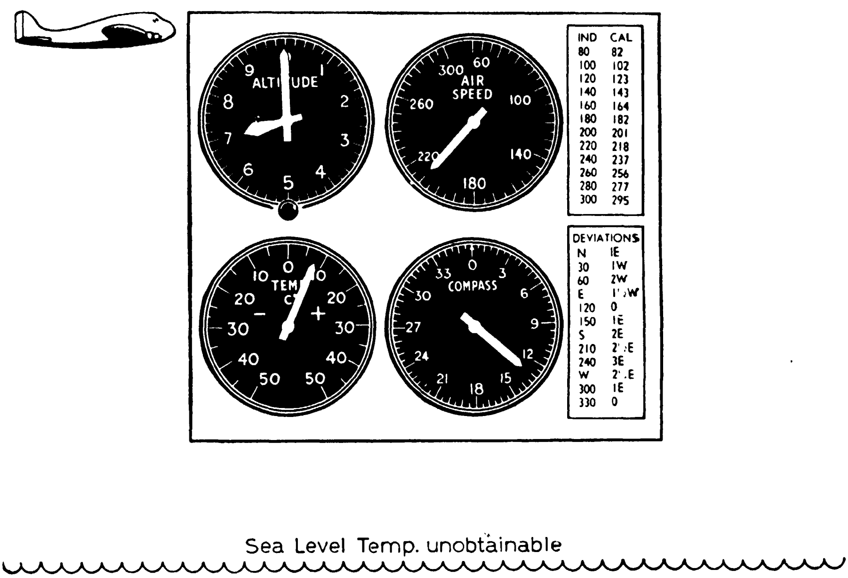


FIG. 90.—Problem in determining altitude.

3. From the navigator's instrument panel shown in Fig. 90, determine the altitude of the plane above sea level.

4. From the navigator's instrument panel shown in Fig. 91, determine the altitude of the plane above sea level.

5. From the navigator's instrument panel shown in Fig. 92, determine the altitude of the plane above sea level.

Pressure Levels above Which Altitudes Are Measured.—A typical aircraft altimeter is shown in Fig. 93. The indicated altitude is 7,660 ft. This may or may not be the correct height of the column of air through which the plane has climbed, depending on whether or not the air column is of standard density. Even if it is, there is nothing to indicate that this altitude is the altitude of the plane above sea level.

Notice the knob at the bottom of the instrument. This is used to make the altimeter read 0 at some definite place; thereafter the instru-

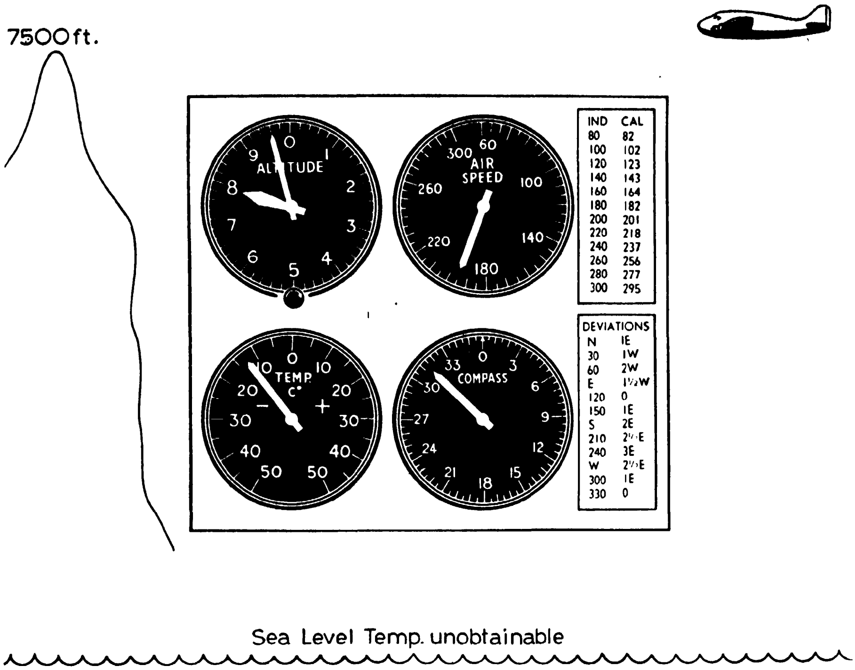


FIG. 91.—Problem in determining altitude.

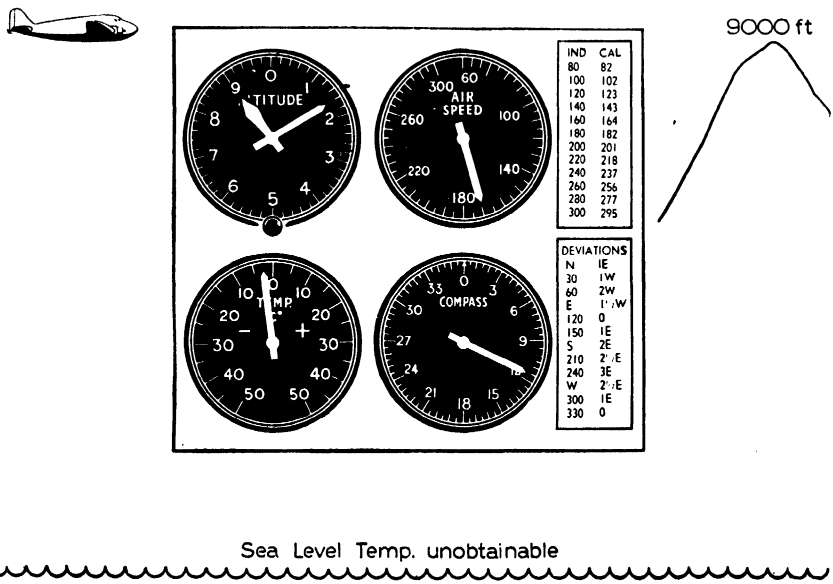


FIG. 92.—Problem in determining altitude.

ment shows an indicated altitude above that place. For example, this instrument can be set to show 0 at sea level, and it can also be set to show 0 at a 2,000-ft. airport. Without knowledge as to the reference level above which the altimeter indicates altitude, any determination of the true height of an air column through which the plane has climbed becomes futile.

The question as to what constitutes a suitable level above which plane altitudes should be measured is debatable. Inasmuch as heights of mountains are always measured above sea level, it would seem advisable for aircraft to use this as a reference level as well. By so doing, both obstruction clearance and vertical separation would be achieved at the same time.

FIG. 93. Kollsman altimeter showing pressure-setting scale.

Refer again to the altimeter in Fig. 93, and notice the air pressure scale on the dial between the figures 2 and 3. When the altimeter was set to read 0, this pressure scale changed from its previous indication to read 29.95. If the altimeter was set to show 0 at sea level, a pressure of 29.95 existed at that level. Thereafter the altimeter indicated height above this air pressure level. If the aircraft flies to an area where the sea-level pressure is not 29.95, the plane will not be 7,660 ft. above sea level though it will still be 7,660 (indicated) feet above the 29.95-in. pressure level.

Figure 94 shows how a plane's altitude above sea level changes even though the indicated altitude is held constant.

If at any time during the flight the pilot obtains information as to the sea-level pressure underneath him, he may rotate the knob at the bottom of the altimeter until the sea-level pressure appears in the pressure window. In so doing he will also move the altimeter hands, and the instrument will then show indicated altitude above sea level. In the absence of any information as to the sea-level pressure, the instrument is adjusted to show indicated altitude above the standard pressure level of 29.92 in. Altitudes shown on the instrument above this standard pressure are known as **pressure altitudes.**

The question as to whether or not the surface pressure above which the pilot originally measured his altitude still exists at the surface beneath him is of vital importance. He may have climbed 7,660 ft. above sea level after take-off, but it must be borne in mind that he really climbed

7,660 ft. above the pressure level existing on the sea at that point. If the sea-level pressure at his new position is 1 in. less than it was where he took off, his plane is approximately 1,000 ft. closer to the surface even though the altimeter still shows 7,660 ft.

It must always be remembered that, in flying from a high-pressure to a low-pressure area without changing the altimeter, the plane will be approximately 1,000 *ft. closer to sea level for every inch of reduced sea-level pressure.*

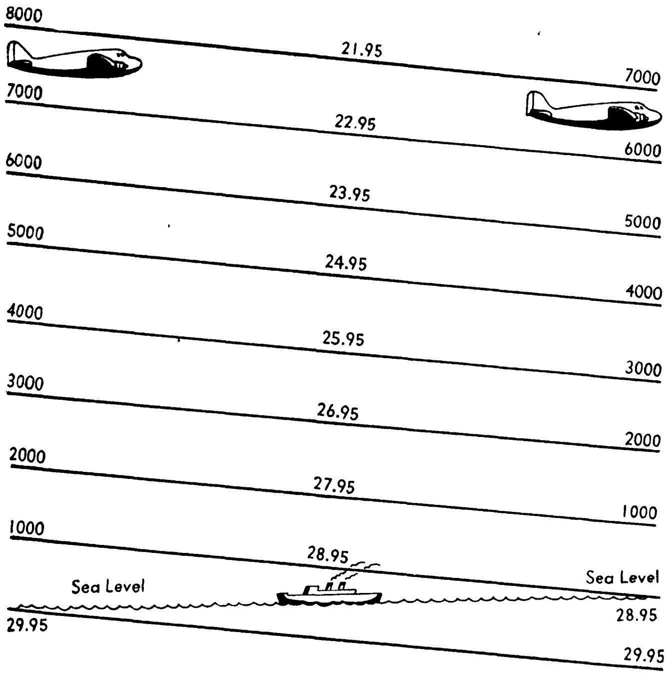


FIG. 94.—Change of altitude of a plane with change of sea-level air pressure.

The Kollsman Number, or Altimeter Setting.—Varying sea-level pressures and temperatures make it impractical for domestic planes to measure their altitudes above sea level. Both these factors must be considered in calculating the height of aircraft above sea level. This necessitates frequent adjustment to the altimeters as planes pass from area to area where these factors differ from standard. If these factors were closely watched, frequent calculation of a plane's true altitude would bring about safe terrain clearance and ensure proper vertical separation. However, if the pilots of two approaching aircraft were to compute their true altitudes under different temperatures and/or sea-level pressures, it would be extremely hazardous for them to attempt to pass.

Vertical separation of domestic aircraft is achieved by requiring all planes in a given area to reckon their altitudes above an arbitrary pressure level. This pressure is supplied by radio. Pilots do not make allowance for nonstandard temperature conditions, because in passing each other their altimeters are equally affected by whatever temperature exists.

The weakness of this system lies in the fact that safe terrain clearance is not guaranteed. To pass an approaching aircraft simply requires that both pilots maintain indicated altitudes above a common reference level; to clear a mountain safely requires accurate knowledge of the plane's altitude above sea level. The pressure level above which the altitudes of domestic aircraft are reckoned is known as the **Kollsman number** or **altimeter setting.**

The altimeter setting, or Kollsman number, is difficult to define, for it is really the sum of two pressures. It is the sum of (1) the actual air pressure bearing down on the reporting station and (2) the pressure exerted by an *assumed standard column of air* reaching down from the reporting station to sea level. The altimeter setting *may* on occasion be sea-level pressure. Obviously, if the reporting station is at sea level, no pressure from an assumed column of air is added to the actual air pressure at the sea-level base. It is also possible for the altimeter setting to agree closely with the correct sea-level pressure when standard temperature conditions prevail at the reporting station.

Unless the altimeter setting comes from a sea-level station in the vicinity of the plane, the pilot is not to assume that his corrected altitude is measured above the same reference level (sea level) that is used in measuring the heights of mountains.

An explanation as to how the altimeter setting is obtained will serve further to clarify the student's idea as to just what it is and will at the same time illustrate its extreme utility. Except for minor refinements, the altimeter setting at any airport may be obtained as follows:

An altimeter similar to that aboard the aircraft is placed at the airport runway level. The altimeter-setting knob is rotated until the face of the altimeter shows the exact elevation of the field above sea level. As the knob is rotated, the numbers in the pressure window keep changing. The number finally appearing when correct airport altitude is indicated is the altimeter setting. This is the altimeter setting that is broadcast to planes in flight; this is the number that pilots set on their cockpit instruments. Actually, the airport makes an allowance for the height of a landed plane's altimeter.

If the temperature at the airport is standard, the altimeter setting will probably be in close agreement with sea-level pressure for that locality; but the pilot, insofar as his landing problem is concerned, is

not greatly interested in this matter. For his part, he is satisfied to know that an instrument at the airport, similar to the one in his plane and set to the same altimeter setting, indicates the exact elevation of the field upon which he is about to land.

Thus we find that the chief merit of the altimeter setting lies in the fact that by its use pilots may descend through any temperature conditions above an airport with the assurance that *when they finally approach* that airport in preparation for a landing their altimeters will show the plane's correct altitude.

One apparently unavoidable weakness of the altimeter setting is that altitudes shown on the instrument are apt to be correct only when

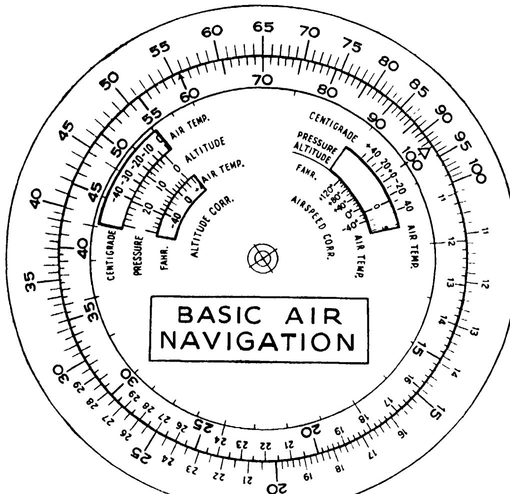


FIG. 95.—Computer solution to Salt Lake City problem.

the plane is about to land at the airport from which the setting was furnished. The following example will serve to illustrate the point:

A pilot, making an instrument approach at Salt Lake City, Utah, is unable to climb more than 11,000 ft. An altimeter setting of 30 in. has been furnished from this airport, 4,220 ft. above sea level. The pilot reasons that since his altimeter will read correctly when he lands it cannot be very much in error at his indicated altitude. The temperature at Salt Lake City is reported to be $-12°C$. The outside temperature at the plane's altitude is $-24°C$. Let us determine the true altitude of the plane.

The computer solution to this problem is shown in Fig. 95. The indicated altitude, 11,000 ft., less the altitude of the airport, 4,220 ft., shows the height of the air column, 6,780 ft. The mean altitude of the air column is 7,610 ft., obtained by adding the indicated altitude to the

airport altitude and dividing by 2. The observed mean temperature of the column of air above the airport is −18°C.

Using scale *C* and *D*, set 7,610 opposite −18°C. Read the correct height of the air column on the outer scale *A* opposite 6,780 on the inner scale *B*. The plane is 6,333 ft. above the airport, and this figure added to the altitude of the airport shows the true altitude of the plane to be 10,553 ft. There is a mountain 10,585 ft. high about 30 miles south of Salt Lake City.

Zero Landing System.—Some of the domestic air lines use an altimeter for landing purposes that differs in some respects from the instrument employed for cross-country work. One such altimeter is shown in Fig. 96. This altimeter is used in the zero landing system, in which the hands of the altimeter read 0 on landing regardless of the elevation of the airport.

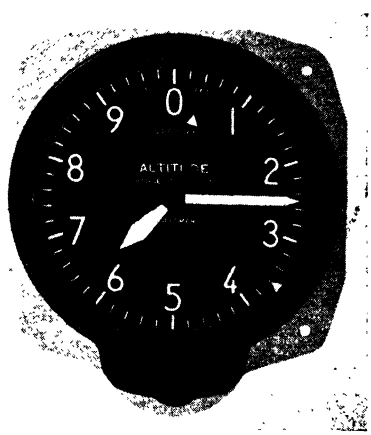


Fig. 96.—Kollsman altimeter with pointers.

The instrument is furnished with two triangular white pointers; one of these moves around the circumference of the dial, indicating hundreds of feet, and the other moves around the inner portion of the dial, indicating thousands of feet. If a plane takes off from sea level under standard conditions, these pointers and the altimeter hands register 0. If the plane takes off from a 5,000-ft. field under standard conditions with altimeter hands set to 0, the triangular pointers, or indexes, will read 5,000 ft. Taking off from the same field under abnormal temperature and/or pressure conditions with altimeter hands set to 0, the indexes will indicate an altitude other than the field elevation. The altitude of the field as indicated by the indexes under this condition is the **pressure altitude** of the airport.

If a pilot is coming in for a landing, he may request this pressure altitude over the company radio and, having received it, rotate the knob of his altimeter until the indexes show it. The altimeter hands will then indicate his elevation above the field within very close limits. As the plane descends into the temperature surrounding the airport, its indicated elevation above the field will become more and more exact, and upon landing the hands should read 0, provided, of course, the instrument functions without error.

Occasionally, such altimeters are equipped with barometric scales as well as indexes, but the principle of operation is the same. When such

an instrument is adjusted to show pressure altitude of the field by means of the indexes, the barometric scale shows the actual air pressure at the airport, not the sea-level pressure for that locality.

Air-speed Indicators—Their Function.—In registering air speeds the air-speed indicator acts as a differential pressure gauge, since it records in terms of speed the difference between the head pressure built up by the plane as it travels through the air and the static (still) air pressure surrounding it.

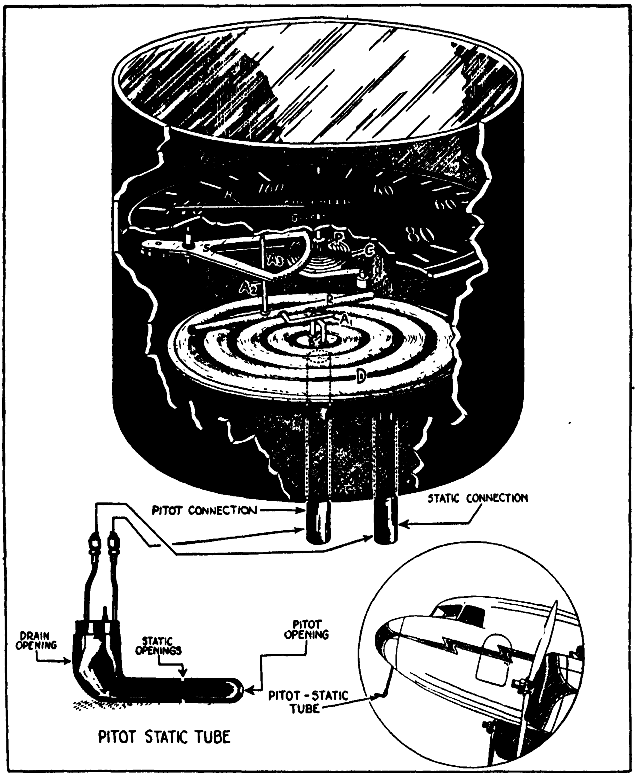


FIG. 97.—Inside view of Kollsman speed indicator.

The head pressure builds up as the speed of the plane increases; the difference between this and the static pressure surrounding the plane is recorded as speed. A diagram of a Kollsman air-speed indicator is shown in Fig. 97.

Notice the **pitot-static tube** used with the instrument. The head pressure is carried to the instrument from the opening at the tip of the tube, and static air-pressure openings in the side of the tube permit entry of the static pressure uninfluenced (in normal flight altitude) by increases or decreases in the forward speed of the plane.

The Pitot connection goes to the inside of the diaphragm. The static connection goes to the inside of the case. This puts the two sides of the diaphragm under different pressures (Pitot pressure inside and static pressure outside), causing its expansion. The wire *B* and the arm A_1 are lifted, turning the rocking shaft *R*. Arm A_2, which is a part of the rocking shaft unit, is moved against arm A_3, which is fixed to the sector *S*, turning the sector and so turning the pinion *P*, which is a part of the staff *G*. The hand *H* is on the staff *G*, as is the hairspring *C*. The force of this spring *C* keeps all parts tight against one another.

Air-speed indicators are designed to indicate true air speed in standard sea-level-density air. Standard sea-level density exists when the pressure is 29.92 in. and the temperature is 59°F. (15°C.). Other combinations of pressure and temperature will produce the same density. In general, however, the temperature-pressure relationship is such that at altitudes above sea level the air density is less than that in which the instrument is designed to show true air speed. A plane cruising in this thin air fails to build up as much head pressure as it would at sea level, and a less than true air speed is indicated on the face of the instrument.

In the absence of a computer an approximate true air speed may be obtained by increasing the indicated air speed 2 per cent for every 1,000 ft. of altitude above sea level.

Example: The air-speed indicator reads 200 m.p.h. at a true altitude of 10,000 ft.

Required: The true air speed.

Procedure: 2 per cent $\times$ 200 m.p.h. = 4.0 miles; 4 $\times$ 10 = 40-mile corr. 200 + 40 = TAS, 240 m.p.h.

Use of Computer for Obtaining True Air Speeds.—In practice a computer is always used for correcting the face reading of the air-speed indicator to true air speed. It should be mentioned at this point that there is usually an instrumental error to take into consideration first, since no two air-speed indicators are mechanically identical. Normally this instrumental error will be found posted beside the instrument. The computer is used to make a *further* correction for flight-altitude temperature. An example will serve to illustrate the procedure.

Example: The altitude of the plane is 10,000 ft., and the temperature is +10°C. The face reading of the air-speed indicator is 160, which with an instrumental error applied becomes 165.

Required: The true air speed.

Procedure: Use the air speed correction scale on the circular slide rule. Rotate the inner disk until the altitude of the plane is opposite the temperature. The number on the outer slide-rule scale opposite 165 on the inner slide-rule scale is the true air speed. *Ans.:* 197.

Remarks: Strict accuracy calls for a prior determination and use of pressure altitude. Pressure altitude is the face reading of the altimeter when it is set to show altitude above the pressure level of 29.92 in. (1,013 mb.). If the altimeter happens to be set to a pressure between 29.75 and 30.25 in., the face reading of the instrument could be used for this purpose with little resulting error. That

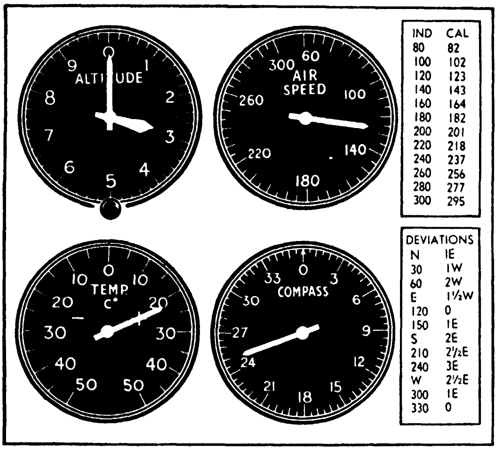


FIG. 98.—Problem in determining true altitude and true air speed.

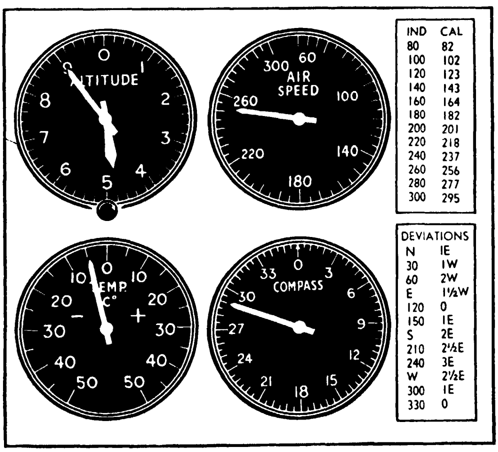


FIG. 99.—Problem in determining true altitude and true air speed.

is, a variation of 100 or 200 ft. in the pressure altitude will not materially affect the accuracy of the resulting true air speed.

In Figs. 98 to 102 the navigator's instrument panel is shown. Determine the true altitude and true air speed from the data furnished by the instruments.

Compasses—True Headings—Compass Headings—Total Compass Error.—So far all directions have been considered as true directions. In

any general discussion of tracks, winds, and headings this has certain advantages, since the discussion then applies generally to the operation of all aircraft. After the plane has been cleared for its destination, however, the navigator is forced to consider headings as being not only true but compass headings as well. That is, though the flight plan may call

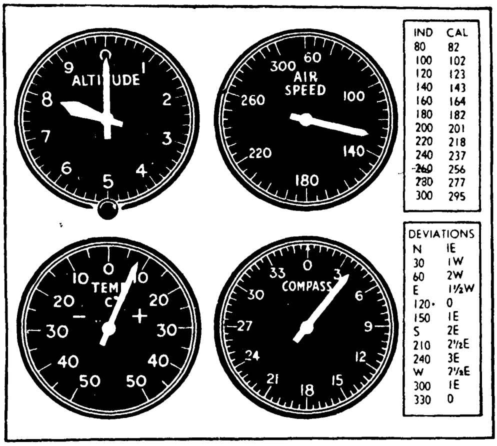


FIG. 100.—Problem in determining true altitude and true air speed.

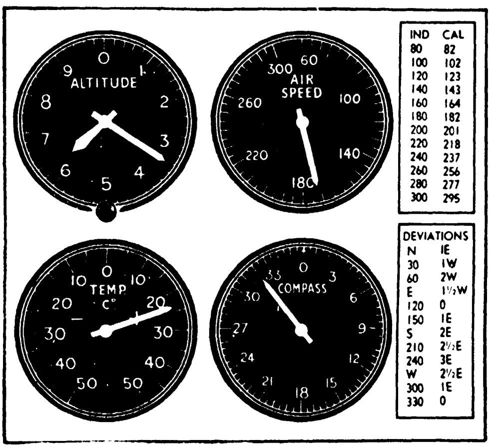


FIG. 101.—Problem in determining true altitude and true air speed.

for the maintenance of a certain true heading, there is no assurance that this can be done by heading the plane in that direction *as shown by the compass*. Aircraft compasses do not indicate true directions. Consequently, before posting the compass heading to be steered, allowance must be made for any difference between the true direction in which the plane is to be headed and the compass direction. It is not unusual for

an aircraft compass—or any magnetic compass—to point out directions 30° different from true directions, and obviously such a difference or even lesser ones cannot be ignored. The compass indication of *true* north

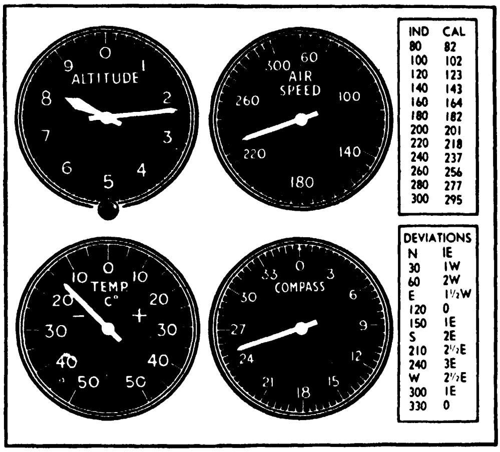


FIG. 102.—Problem in determining true altitude and true air speed.

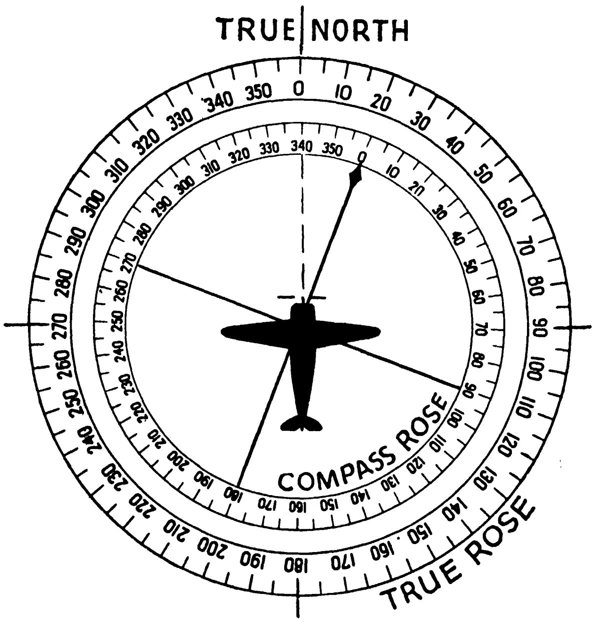


FIG. 103.—Easterly compass error.

may, for example, be 340°. The difference between the two is known as the **total compass error.** *The total compass error is the difference between a true direction and the compass indication of that direction.*

Study Fig. 103. The outer circle, or true rose, shows true north, and the plane is headed in that direction. The inner circle shows the *compass* rose seen by the pilot; by that rose the plane is headed 340°. The student should compare the two roses and note that the north end of the *compass* points to the east of *true* north; it is for this reason that the total error in this case is termed "east." Whenever easterly error exists, the compass heading is always numerically less than the true heading.[1]

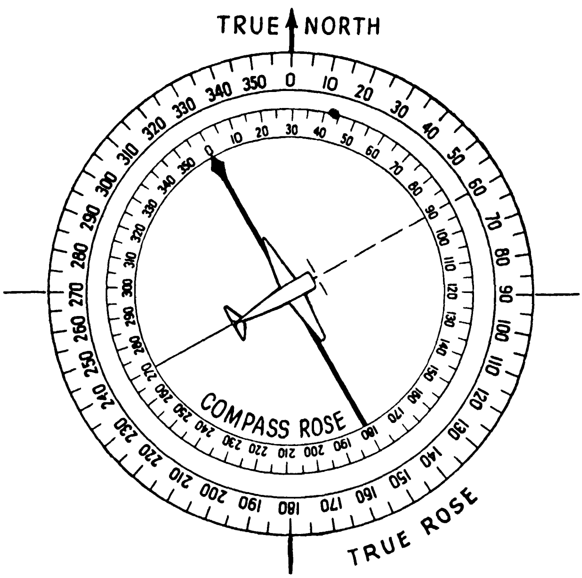


FIG. 104.—Westerly compass error.

In Fig. 104 the outer rose again is a true rose showing true directions, and the plane, according to this rose, is headed 60°. By compass, however, the plane is headed 90°. This is brought about by the fact that the north end of the compass needle in this case points 30° west of true north, *i.e.*, a total compass error of 30° west exists. The question as to when easterly or westerly error exists will be taken up directly; for the time being the point to be emphasized is the manner in which allowance is made for that error. The following problems will be of assistance:

PROBLEMS

State the compass heading, and illustrate the problems:

1. The true heading to be maintained is 150°; the compass error is 22° east.

[1] The author, at the risk of criticism, supports this rule. The student is assumed to have sufficient reasoning power to know that, in order to steer 10° true with an 11° easterly error, a compass heading of 359° would have to be maintained.

2. The true heading to be maintained is 265°; the compass error is 15° west.
3. The true heading to be maintained is 179°; the compass error is 5° east.
4. The true heading to be maintained is 350°; the compass error is 9° west.
5. The true heading to be maintained is 350°; the compass error is 11° west.
6. The true heading to be maintained is 17°; the compass error is 20° east.

If there were no disturbing magnetic influences around the compass, such as electric cables, magnetized steel members of the ship, panel lights, microphones, and relatively soft iron structural metal—all of which tend to produce error in the compass—we might say that this total error is produced by one thing alone. We might say, and correctly, that the error of the compass is due solely to the fact that the magnetic mass which attracts the north end of the compass needle is not located at the true north geographic pole. It is possible, of course, for a plane to be so situated on the earth that the magnetic north pole and the true north pole line up with each other; in this case through pure chance the north end of the needle points true north, and all true directions are also compass directions. Such is the case near Savannah, Ga., and Cincinnati, Ohio. At Boston, Mass., however, the true and magnetic poles do not line up; a good magnetic compass points 15° west of true north at this city.

This difference or variation in direction between true north and north as shown on an undisturbed magnetic compass is called **variation.** As we stated before, if there were no disturbing magnetic fields on the plane itself that might tend to influence the compass, this variation would be the total compass error. The amount and type (east or west) of this variation may always be obtained from navigation charts; reference to Chart 3060b on page 20 will show the student the variation at any place in the United States. Notice that at Great Falls, Mont., the variation is 20° east.

The line joining all points where there is *no variation* is called the **agonic line;** lines joining places where the *variation is the same* are called **isogonic lines.**

PROBLEMS

1. There is no wind, and the pilot wishes to head 170° true (his track likewise would be 170°) from Great Falls, Mont. If there are no disturbing magnetic influences aboard the plane, what would his compass heading be?

2. Under the same conditions what would the compass heading be out of Boston, Mass.?

Unfortunately, the magnetic disturbances aboard the plane cannot be ignored, for they make the compass deviate from its proper magnetic indications. Sometimes this **deviation** neutralizes in part the effect

of the variation, but on the other hand it may combine with it to increase the total deflection of the needle. The variation is 15° west at Boston and an uninfluenced magnetic compass will point 15° west of true north, but influences aboard the plane may make the compass needle point 5° still further west; in this case the compass is said to have 5° westerly deviation. It is the combination of variation and deviation that produces the **total error** of the compass. In general, the student will do well always to combine these two values and then, in order to determine the compass heading, apply the total compass error to the true heading.

The student might ask whether it would not be possible to neutralize the magnetic influences aboard the plane, *i.e.*, to reduce the deviation to 0 so that the only factor producing error would be the variation of that locality. An attempt is often made to do this by inserting or locating small permanent magnets near the compass in such a manner that they counteract the disturbing influences. However, from what has already been said regarding these disturbing influences, it should be apparent that not all of them may be acting at one time. Panel lights, for example, may not always be turned on, the radio located near the compass may not always be in use, and the magnetism induced in the soft iron members of the plane from the magnetic field surrounding the earth may not be constant. For any given operating condition and place, the deviation-producing forces can be almost entirely eliminated by the judicious use of compensating magnets near the compass, but it must be borne in mind that, if the radio, panel light, etc., which were turned on during compensation, are turned off later, the magnets that neutralized their influence on the compass will themselves produce deviation.

In a subsequent chapter (Chap. X), which the student may omit for the time being unless he intends to compensate compasses, the various procedures usually followed will be discussed. For the present, however, it may be assumed that the known deviations will be found tabulated on a card posted on the instrument panel beside the compass. The deviation indicated there is to be combined with the variation for the locality in order to obtain the total error of the compass. Often, when a given true heading must be maintained for a considerable distance, the navigator will find it necessary to alter the compass heading from time to time as the variation portion of the total compass error changes.

In Figs. 105 to 116 the navigator's panel is shown beside a small chart on which the isogonic lines of variation are shown. The position of the plane has been noted on each of the charts.

Required: From the given data determine

1. The true altitude of the plane.
2. The true air speed.
3. The true heading.

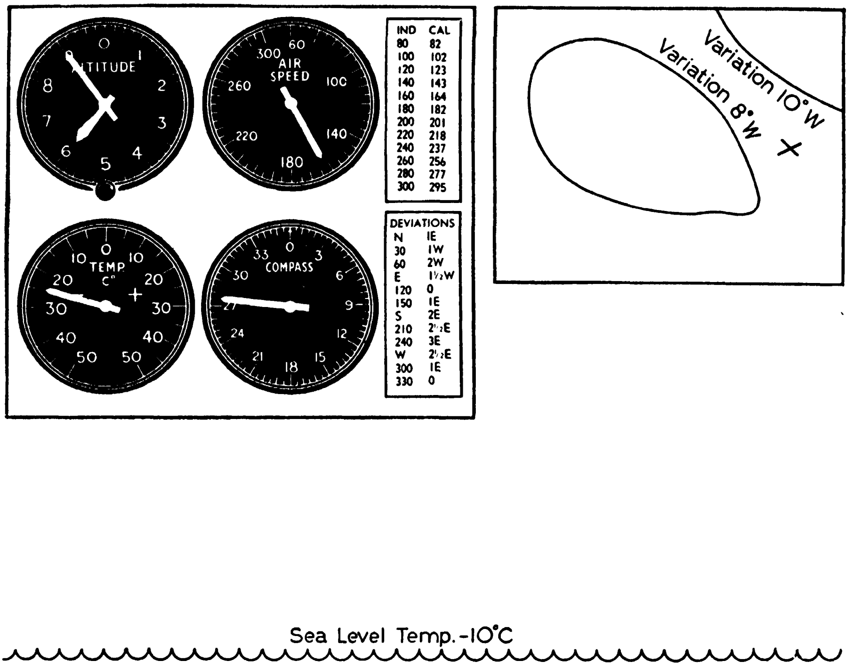


FIG. 105.—Determine true altitude, air speed, and heading.

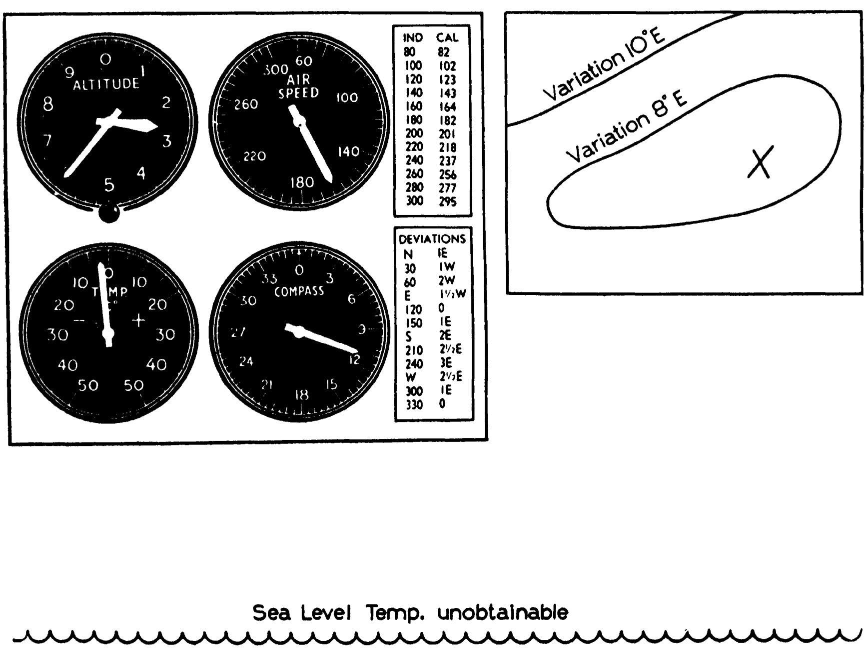


FIG. 106.—Determine true altitude, air speed, and heading.

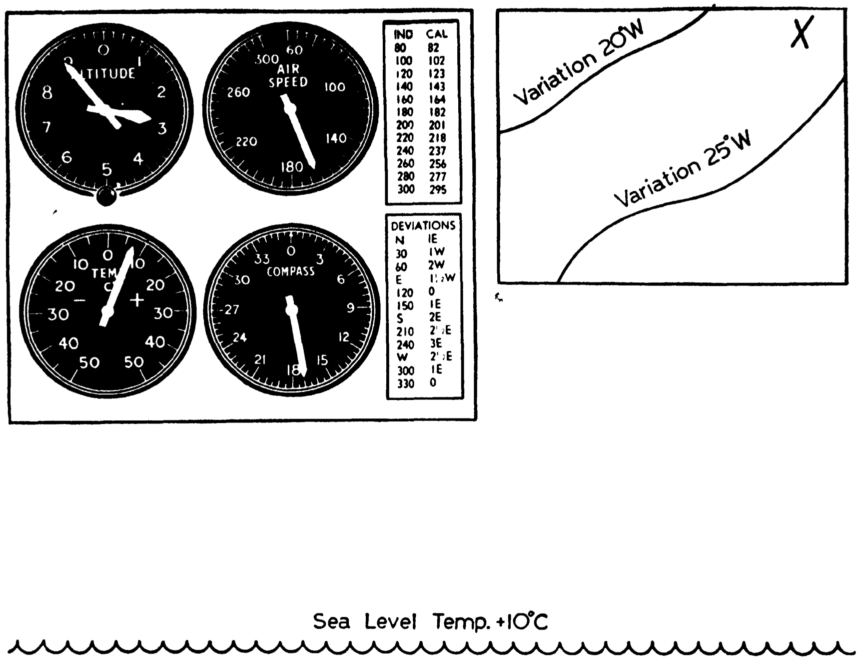


FIG. 107.—Determine true altitude, air speed, and heading.

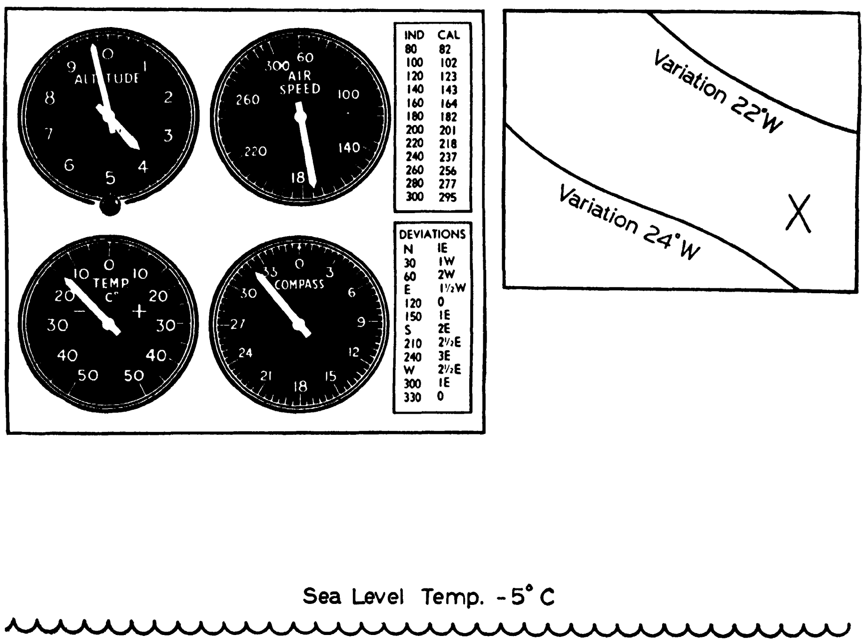


FIG. 108.—Determine true altitude, air speed, and heading.

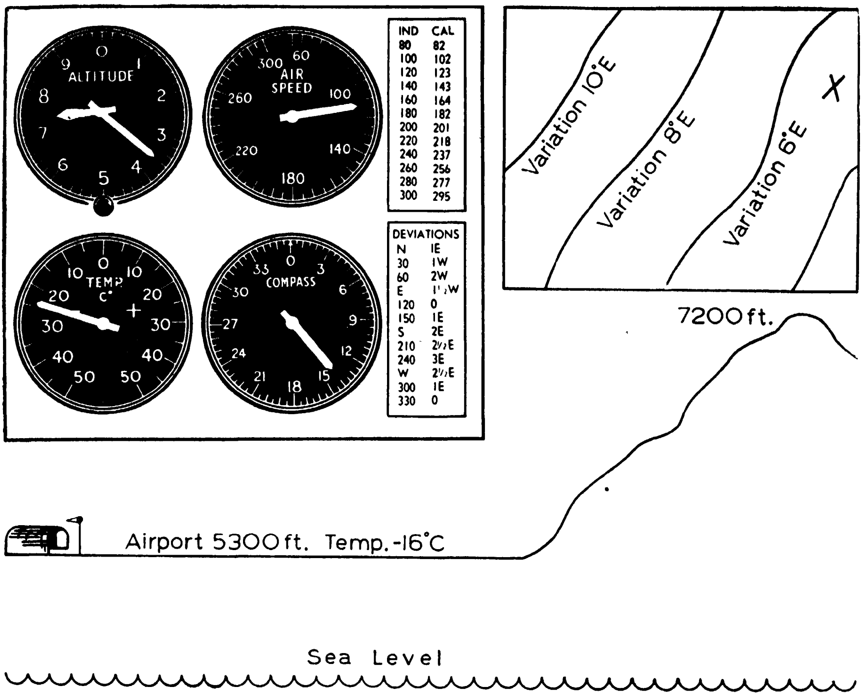


FIG. 109.—Determine true altitude, air speed, and heading.

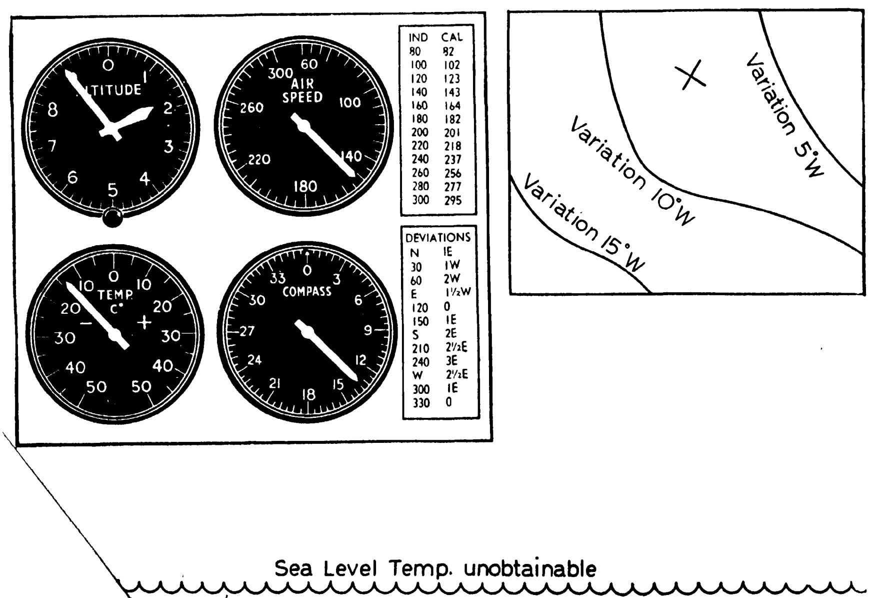


FIG. 110.—Determine true altitude, air speed, and heading.

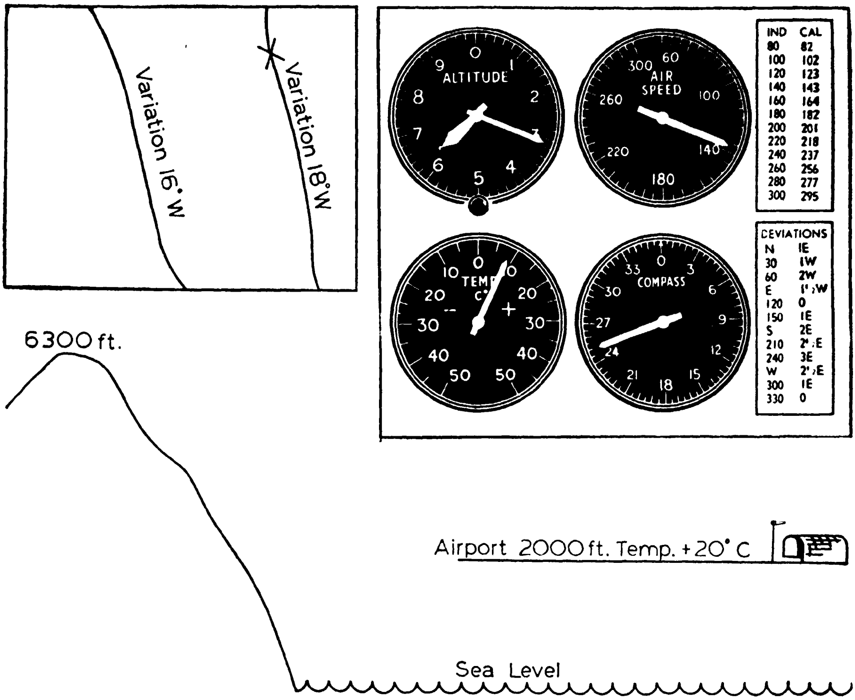


Fig. 111.—Determine true altitude, air speed, and heading.

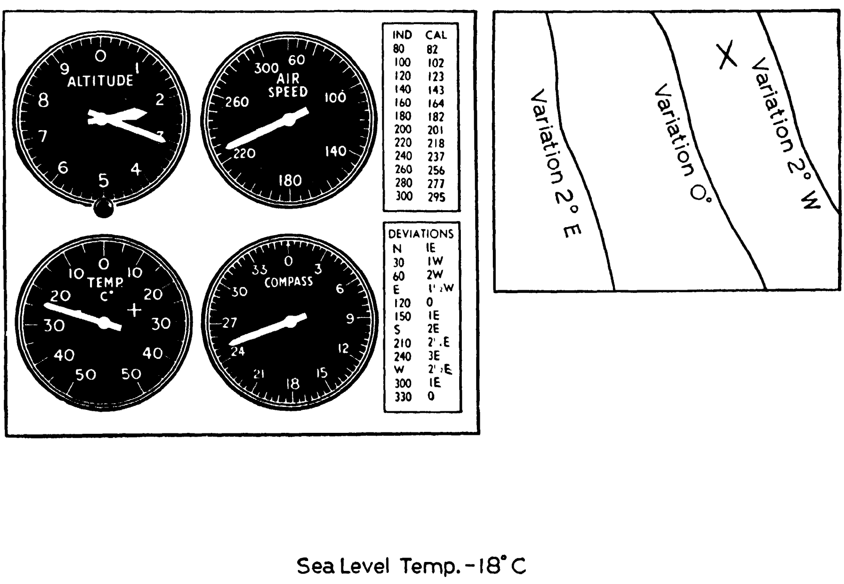


Fig. 112.—Determine true altitude, air speed, and heading.

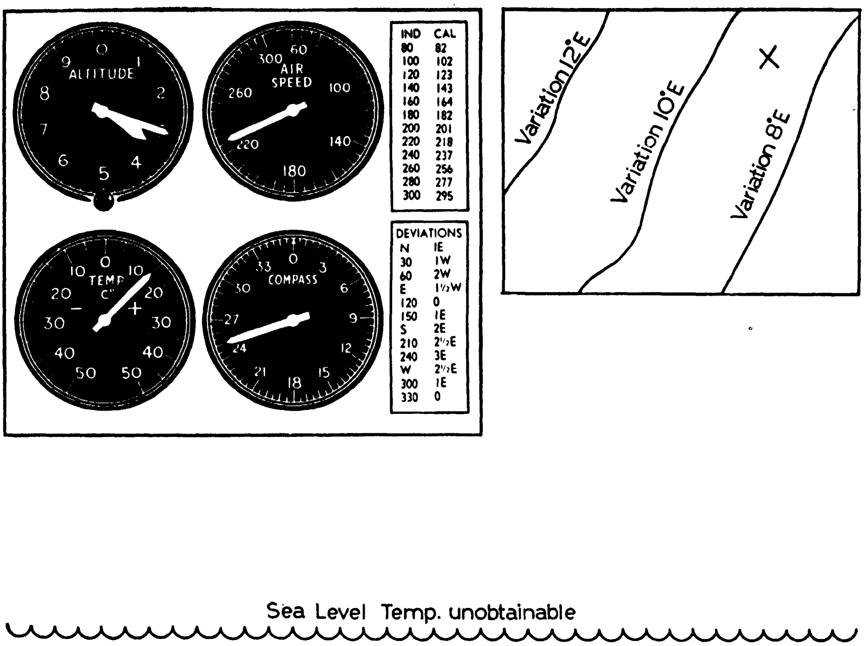


FIG. 113.—Determine true altitude, air speed, and heading.

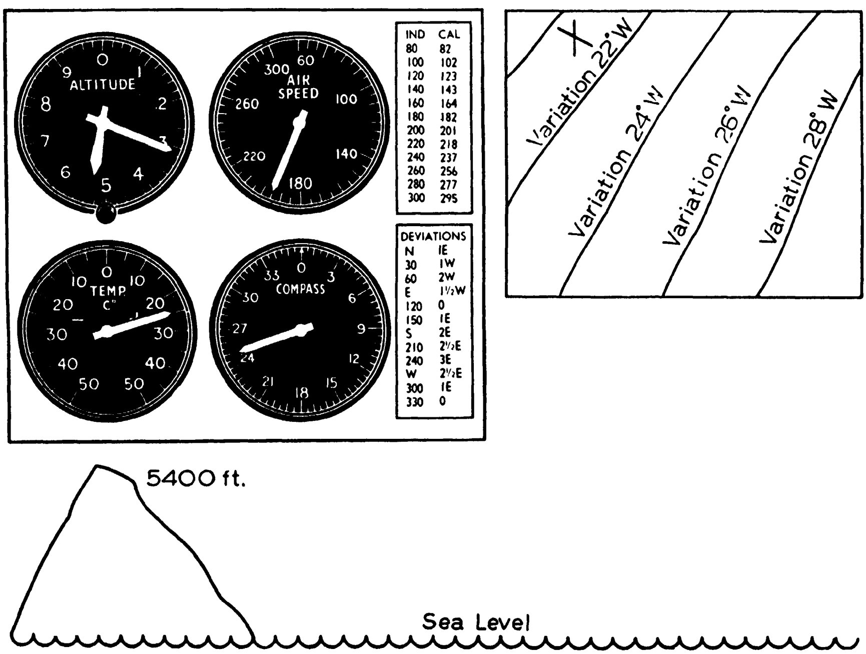


FIG. 114.—Determine true altitude, air speed, and heading.

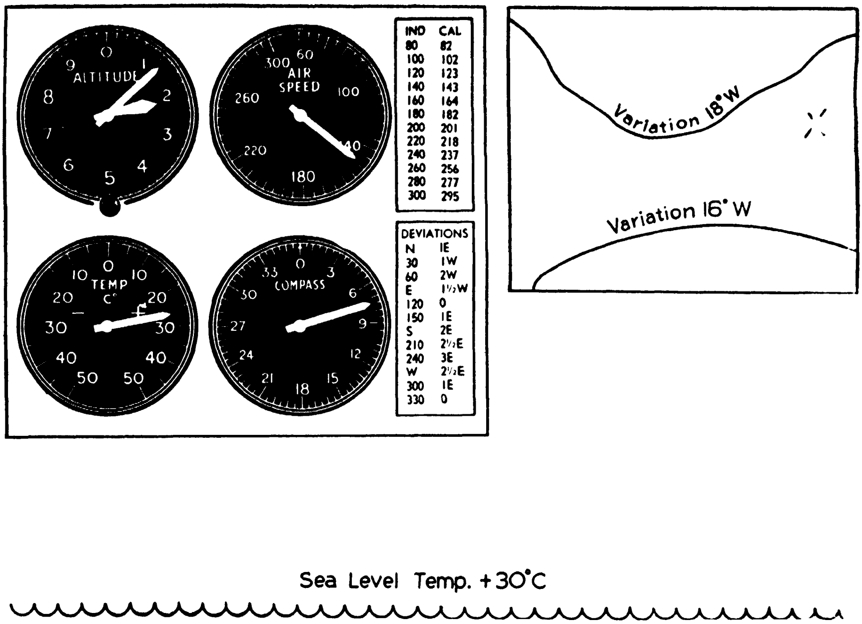


FIG. 115.—Determine true altitude, air speed, and heading.

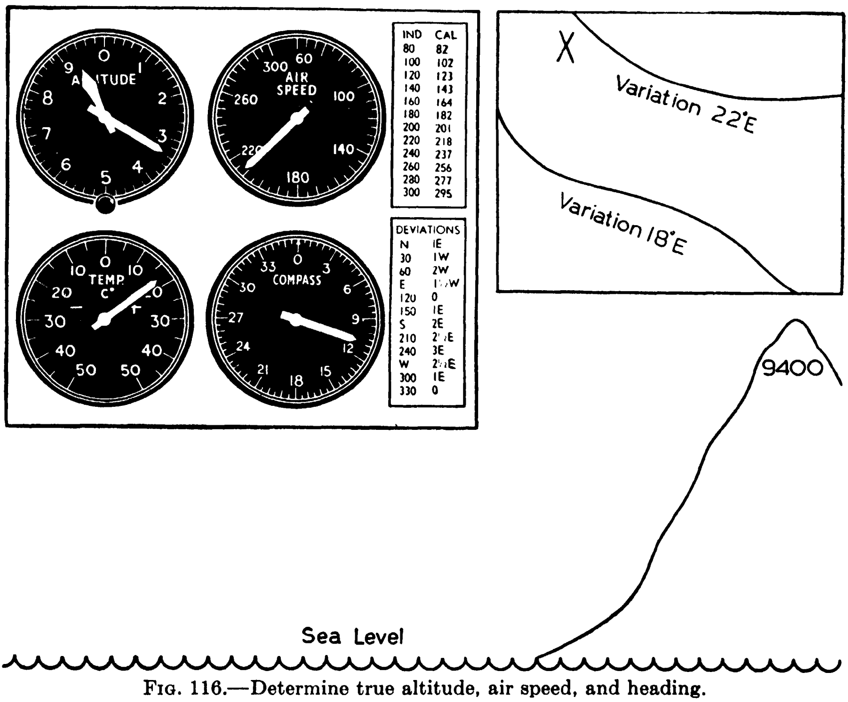


FIG. 116.—Determine true altitude, air speed, and heading.

Remarks: Use the air-speed calibration chart posted beside the air-speed indicator. Use the deviation chart posted beside the compass. Remember that the deviation shown there is to be combined with the variation at the plane's position in order to determine the total compass error.

Drift Indicators.—As long as radio aids to navigation continue to be available, the drift indicator will probably be omitted from the navigation equipment of domestic air-line planes. This is not to say that drift is not obtained during flights of such ships, for it frequently is. For the most part, however, these planes are usually flown along airways, and the drift angle may be readily determined by observing how much left or right of the radio beam the plane has to be steered to keep on track. For example, a plane en route from St. Louis to Kansas City would normally head about 270° by compass in still air. Obviously, if it becomes necessary to steer 280° to keep on the track, a left drift of 10° is being experienced.

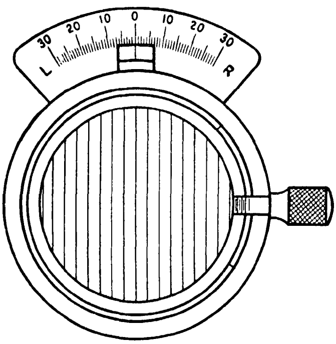


FIG. 117.—Gurley drift-indicator scanning disk.

Military planes and commercial planes on ocean flights are handicapped by their inability to determine drift at will in this manner. Even when radio aids to navigation are available, the navigators of such planes must be prepared to obtain drift by some other means. Great distances may make the radio signals weak and unreliable, and for military reasons the radio station may cease operating altogether.

Various types of drift indicators may be employed; the more elaborate ones are stabilized gyroscopically to ensure accuracy at high altitudes. The essential function of all these instruments, however, is the same. A prominent object, such as a barn, house, tree, or pond, is sighted beneath the plane when over land and a prominent whitecap is sighted when over the sea, and the passage of this object along a series of grid lines is noted. If the object is observed straight ahead, it should, if there is no wind, disappear straight behind the plane. If, however, a strong wind blows from the left, the plane will drift off to the right and the object sighted straight ahead will pass to the left of the aircraft.

It is possible by rotating the scanning piece of the drift indicator to make the sighted object run parallel to the grid lines etched on the surface of the disk. When this is done, the drift angle may be ascertained by noting the angular amount it was necessary to rotate the scanning piece to obtain the parallel movement. Such a scanning disk in shown

in Fig. 117. In practice, the setscrew at the right is unlocked, and the scanning disk is rotated left or right to align the grid lines with the movement of the fixed object on the earth's surface.

A tubular drift sight similar to that used by Pan American Airway's Atlantic Division Clippers is shown in Fig. 118. In principle the operation of this drift indicator is the same as that of any other; the periscopic arrangement is necessary because structural considerations make it inadvisable to install a drift indicator in the bottom of seaplanes. Note the setscrew near the eyepiece at the left of the instrument. This is the setscrew previously mentioned which is unlocked and by means of which the grid piece is rotated. The instrument is installed in the side of the aircraft and is moved outward through a special fitting prior to taking drift observations.

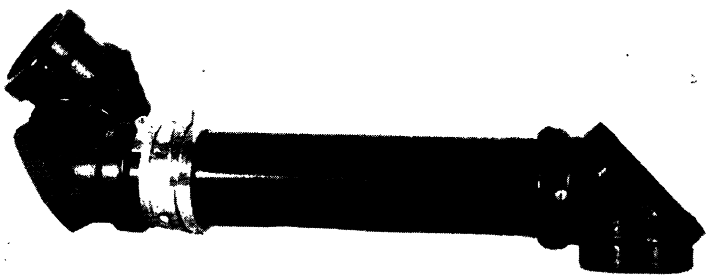


Fig. 118.—Gurley drift indicator.

It is unfortunate in the extreme that textbook instruction fails to give practice and experience in the handling of such instruments. The student must spend some few hours in the air practicing before he really becomes adept in their use. Several "pointers," however, will be mentioned that should shorten his period of training.

In the first place, the eye must be kept focused on some definite object, and this must be followed from the time it enters the field of vision until it leaves the scanning disk. At high altitudes the object appears to travel slowly and, in the instrument just illustrated, will remain in sight for 10 to 20 sec. It is impossible as a rule to obtain an accurate drift with a single observation; usually the surface beneath the plane must be observed closely for about 2 min. During this interval of time perhaps six prominent objects will come into view and be used by the navigator to obtain the drift angle. The average of the several drifts thus obtained is generally accurate to within 1°.

Before taking any of these observations the pilots should be notified in order that they may cooperate by holding the plane steady. A large

plane, like a large ship, has a definite roll period, and much difficulty will be experienced in obtaining an accurate drift if the wings are not held steady. If the left wing is allowed to drop suddenly, a high right drift will be indicated, for the object that should have passed directly beneath the plane will suddenly appear well out toward the left wing tip.

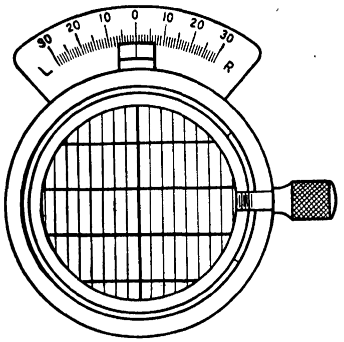


FIG. 119.—Gurley scanning disk with speed lines.

In flying over open water where observations are taken on whitecaps, the eye cannot be taken away from the drift indicator even momentarily; to do so results in loss of whitecap identity.

On a few occasions the author has been obliged to obtain drift by using contrasting surface marks caused by sunlight reflected on the water, but under such conditions accuracy of the first order is not to be expected.

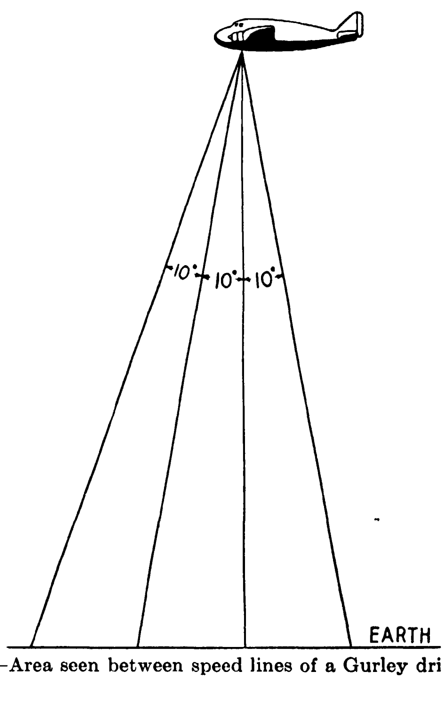


FIG. 120.—Area seen between speed lines of a Gurley drift indicator.

Floating seaweed, however, when observed on a glassy sea, furnishes a very ready means of checking the drift. It lies motionless on the surface

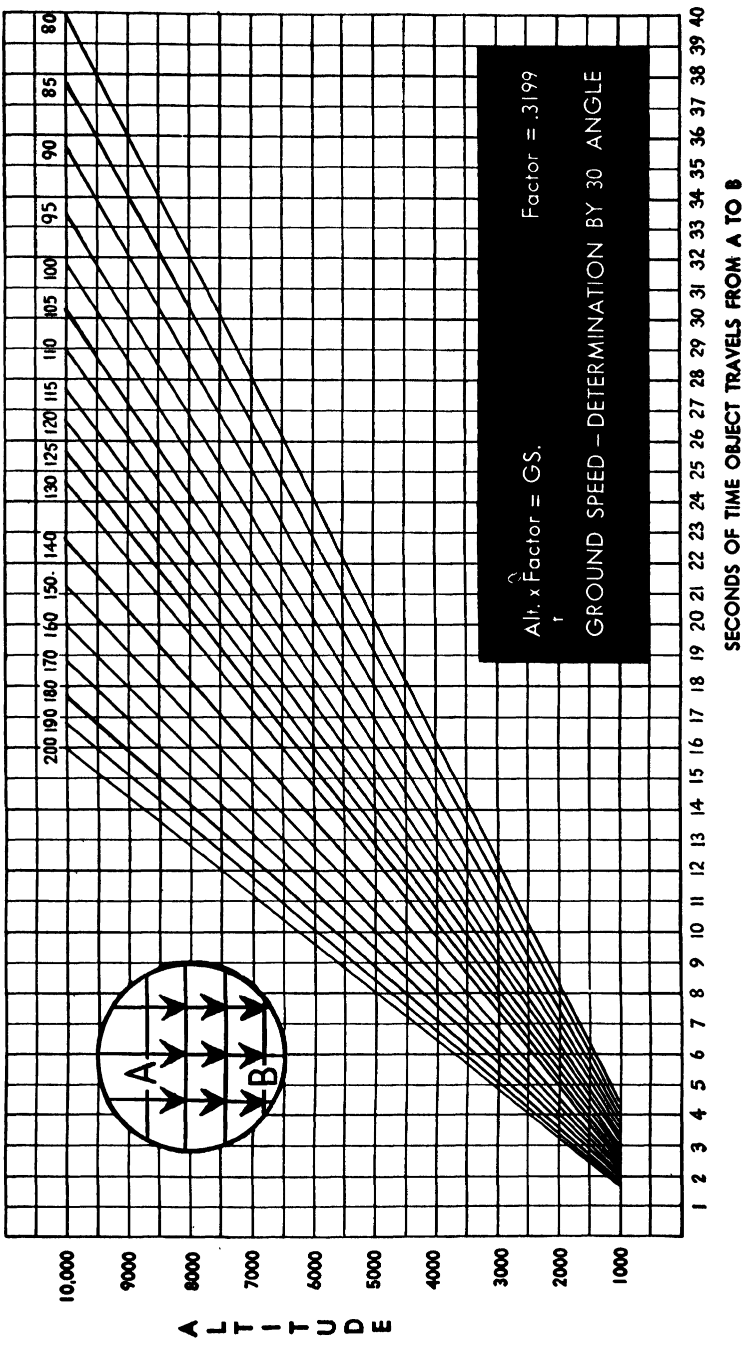


FIG. 121.—Ground-speed graph for use with Gurley drift indicator.

of the sea in patches or shapes different enough in appearance from each other to permit continuous identification.

Determination of Ground Speed with Drift Indicator.—Drift indicators that permit determination of ground speed are used on some commercial planes. The Gurley tubular drift sight just discussed is sometimes equipped with a special scanning disk for this purpose. It is shown in Fig. 119.

At right angles to the thin drift lines etched on the surface of this disk the student will observe four heavy **speed lines.** After the drift setting has been established, a stop watch is used to time the passage of objects across these lines. In the case of the Gurley instrument the speed lines are spaced 10° apart; *i.e.*, the ground observed subtends an angle of 30° at the navigator's eye (Fig. 120).

A study of the figure will show that the actual area seen in the scanning disk will increase with altitude. The exact amount of the surface of the earth visible at any altitude is easily calculated. The navigator need ascertain only the length of time taken by the plane to cross that area in order to obtain knowledge of the ground speed.

In practice a graph such as that shown in Fig. 121 is furnished, and all calculation except the averaging of a series of 10 stop-watch intervals becomes unnecessary. Since the field of vision depends on altitude, it is of great importance to make every known correction to the face reading of the altimeter before using this graph.

PROBLEMS

1. The true altitude of the plane is 8,000 ft.; the navigator times the passage of 10 prominent objects across the first and last speed lines (30°); these intervals when averaged give an average period of time of 16.0 sec.

Required: The ground speed.

Procedure: Enter the graph on the left-hand side at 8,000 ft., follow the line across to 16.0 sec., and read the ground speed on the diagonal.

Ans.: 160 m.p.h.

2. The indicated altitude of an aircraft is 6,400 ft.; the temperature is −10°C. The navigator times the passage of whitecaps between the first and last speed line (30°), and the average time is 12.4 sec.

Required: The ground speed.

Procedure: Correct the indicated altitude for the temperature condition, enter the graph with the correct altitude and time, and read the ground speed on the diagonal line.

3. The navigator's instrument panel is shown in Fig. 122. Whitecaps are timed between the first and last grid lines (30°), and the average time is 16.8 sec.

Required: The ground speed.

4. The navigator's instrument panel is shown in Fig. 123. The average drift is 11° right and an average stop-watch time of 14 sec. is obtained from timing a 30° movement of the whitecaps. The variation is 14° west.

Required: The wind direction and velocity.

Remarks: Enough data are at hand to solve this problem by using solution 4 of the triangle of velocities (page 8).

Procedure: Correct the indicated air speed to calibrated air speed by applying the correction posted beside the instrument. Correct the calibrated air speed

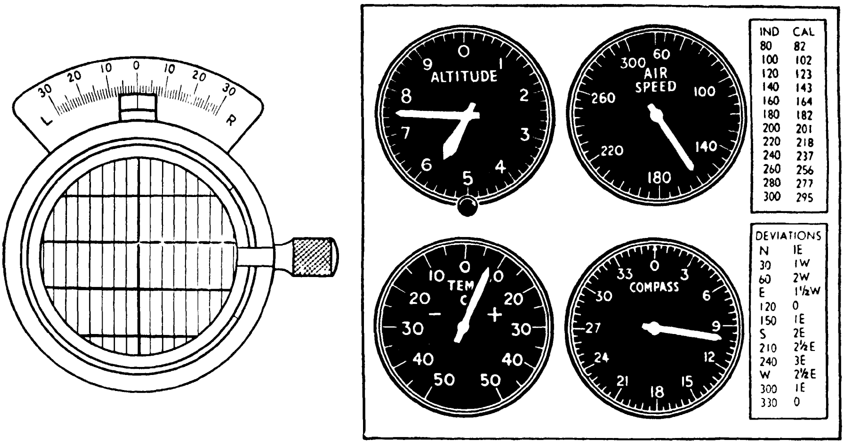


FIG. 122.—Problem 3.

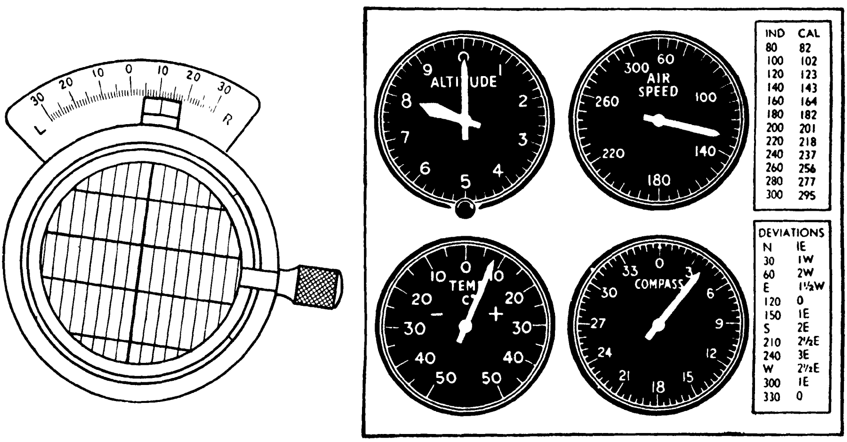


FIG. 123.—Problem 4.

to true air speed by making allowance for temperature. Correct the indicated altitude to true altitude by making a correction for temperature. Correct the compass heading to true heading by applying the total error of the compass.

5. The navigator's instrument panel is shown in Fig. 124. The average drift is 6° left and an average stop-watch time of 16.2 sec. is obtained from timing a 30°movement of clumps of seaweed. The variation for the locality is 5° east.

Required: Using the same procedure as in Prob. 4, determine the wind direction and velocity.

6. The navigator's instrument panel is shown in Fig. 125. The average drift is 10° left, and the average stop-watch time is 12.6 sec., obtained from averaging a series of observations on a 30° movement of small icebergs. The variation is

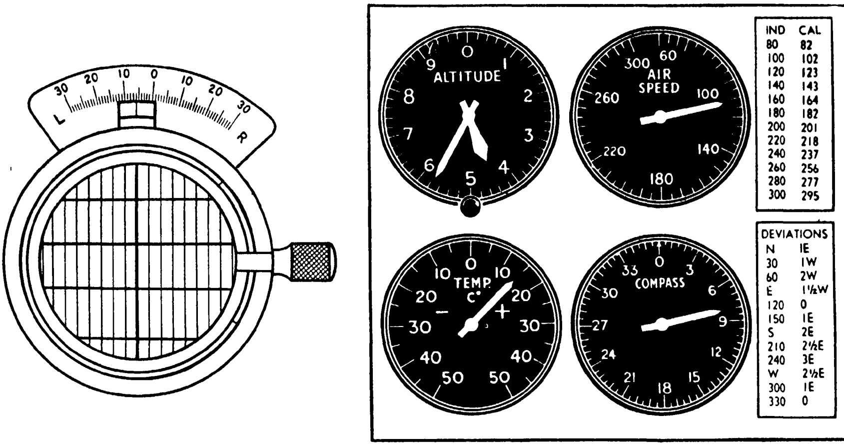


FIG. 124.—Problem 5.

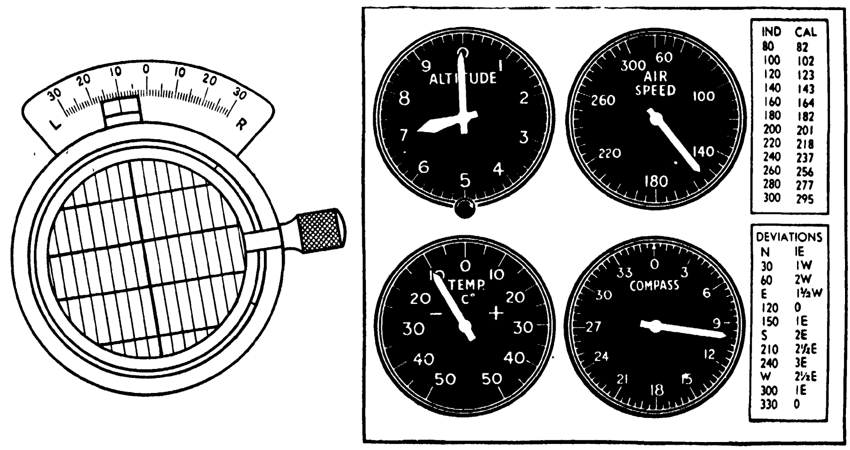


FIG. 125.—Problem 6.

32° west. Determine the wind direction and velocity. The desired track is 120. Use the wind, and determine the necessary true heading.

7. The pilot of a plane at position X in Fig. 126 times whitecaps and obtains an average stop-watch interval of 15.6 sec. The drift is 4° left. Determine the wind direction and velocity and compass heading to make track 302°.

The drift indicator just discussed is a very satisfactory unstabilized unit for daytime observations over open water. It may also be used to

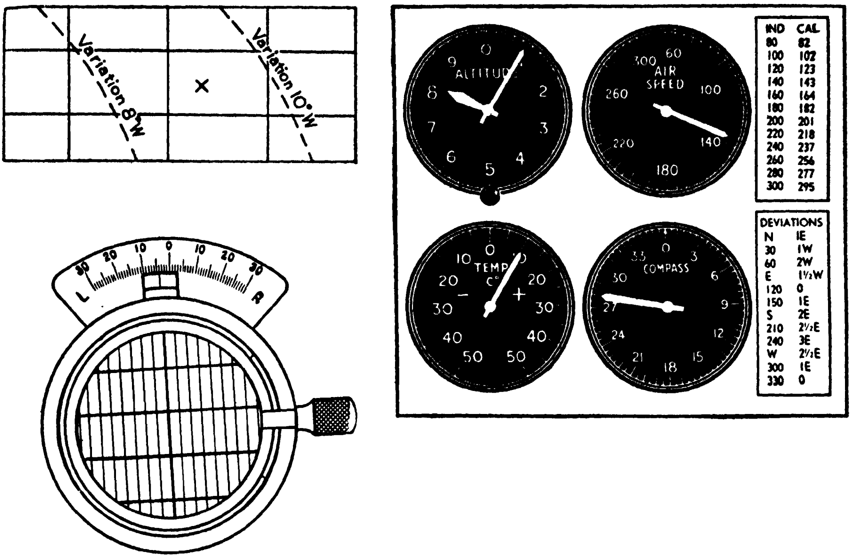


Fig. 126.—Problem 7.

Fig. 127.—Gurley rear-vision drift indicator.

advantage over land both day and night, but at night some illumination on the surface, such as village lights, must be used. Over the open sea this type of drift indicator cannot be used at night, for no lights are visible below. If a water light were to be thrown overboard from the plane, it would land far astern and out of the field of vision. Another type of instrument manufactured by the Gurley Company is used in the Pan American Clippers and is shown in Figs. 127 and 128 in two designs.

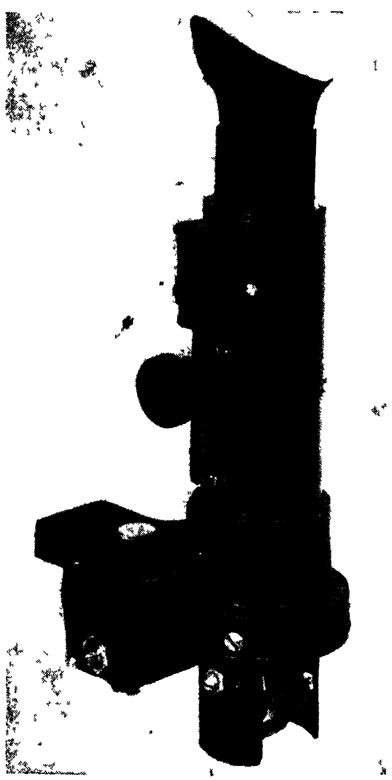
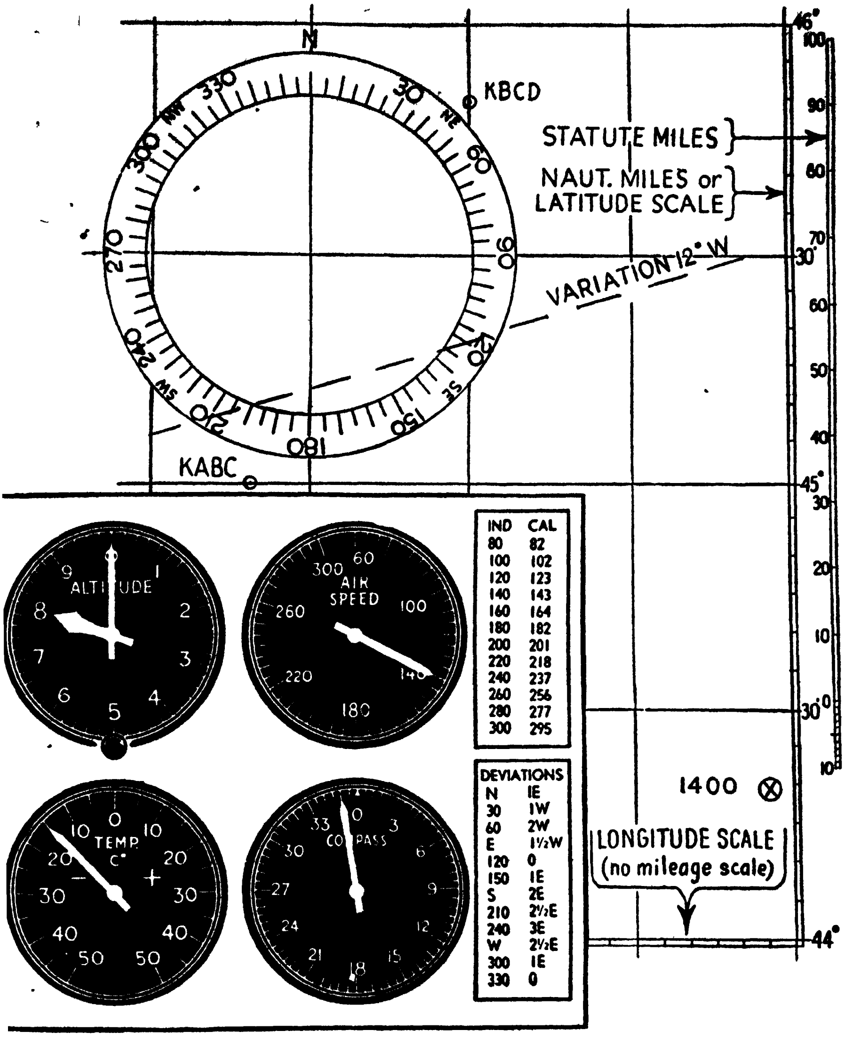


FIG. 128.—Gurley rear-view drift indicator (modified).

These instruments, mounted in a trap door in the trailing edge of the wing, enable the navigator to see an object on the surface behind the aircraft. In daytime, surface objects are shown in sharp detail, and at night a water light dropped overboard from the plane can be seen easily as it burns on the surface. The first of these instruments (Fig. 127) is rotated left or right until the water light is seen on the line etched on the surface of the mirror; the mirror itself may be raised or lowered so as to look far off toward the horizon or sharply downward. Owing to this instrument's great field of vision, the water light shows little or no tendency to run parallel to the etched lines but appears stationary on it until it burns out. The second instrument (Fig. 128) is a modification of the first, and in principle it works in exactly the same way. Its chief advantage lies in the fact that the prism is shielded from any stray wind currents; absence of wind vibration results in even greater clarity of vision. A lens system that produces considerable magnification is built into this drift indicator.

An instrument such as this that enables the navigator to see the surface of the water behind the plane is absolutely essential whenever there is insufficient surface wind to form whitecaps or when darkness obscures the surface. Under these circumstances some object must be thrown overboard from the plane—such as a container of powdered bronze in daytime or a float light at night—in order to permit observation of drift. Several drift bombs and water lights are shown in Fig. 129.



IND	CAL
80	82
100	102
120	123
140	143
160	164
180	182
200	201
220	218
240	237
260	256
280	277
300	295

DEVIATIONS	
N	1E
30	1W
60	2W
E	1½W
120	0
150	1E
S	2E
210	2½E
240	3E
W	2½E
300	1E
330	0

FIG. 189.—Problem 4.

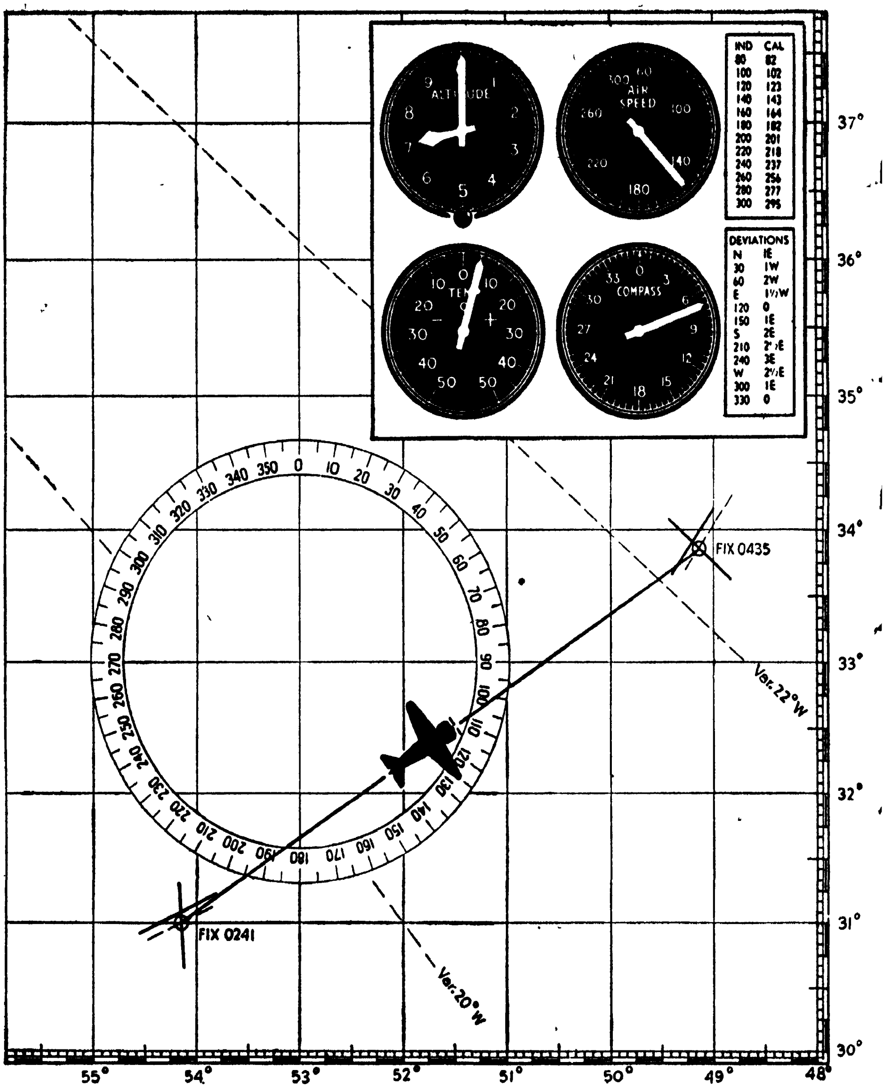


Fig. 201.—Problem 10.

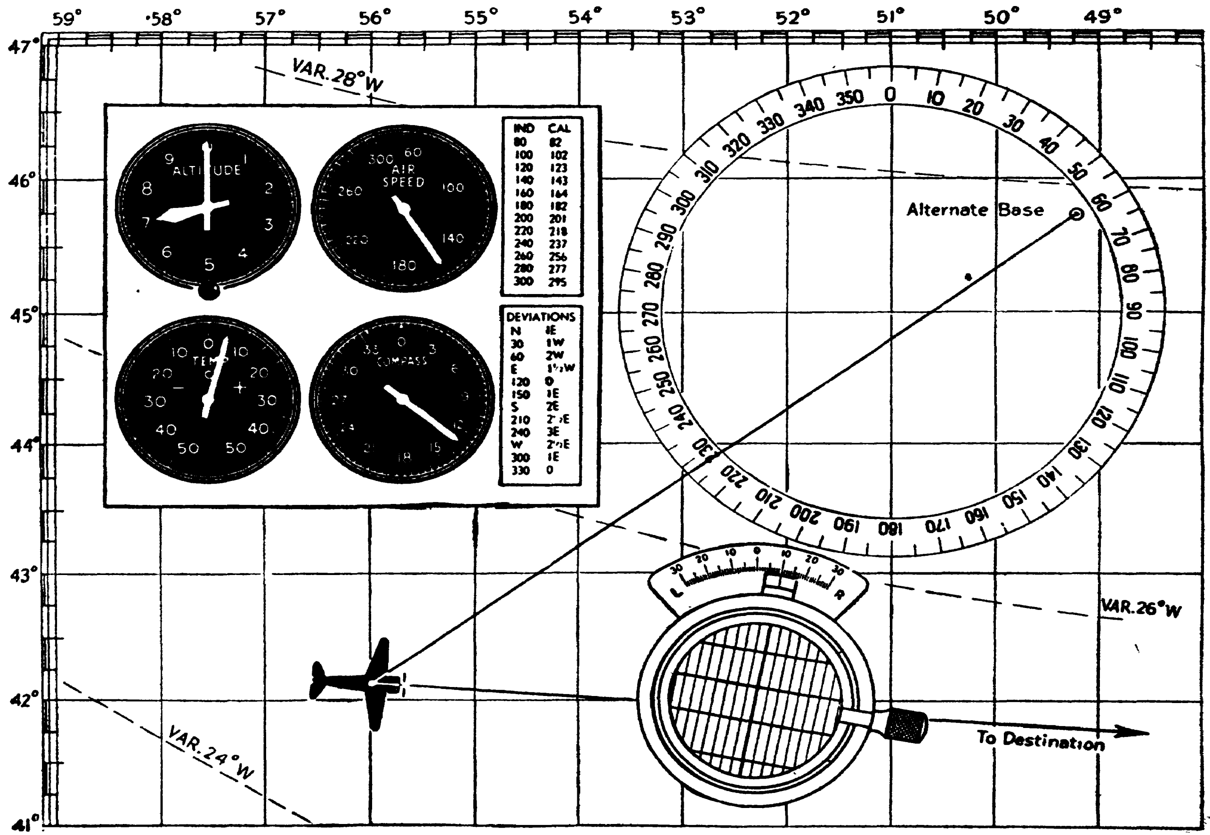


Fig. 233.—Problem 5.

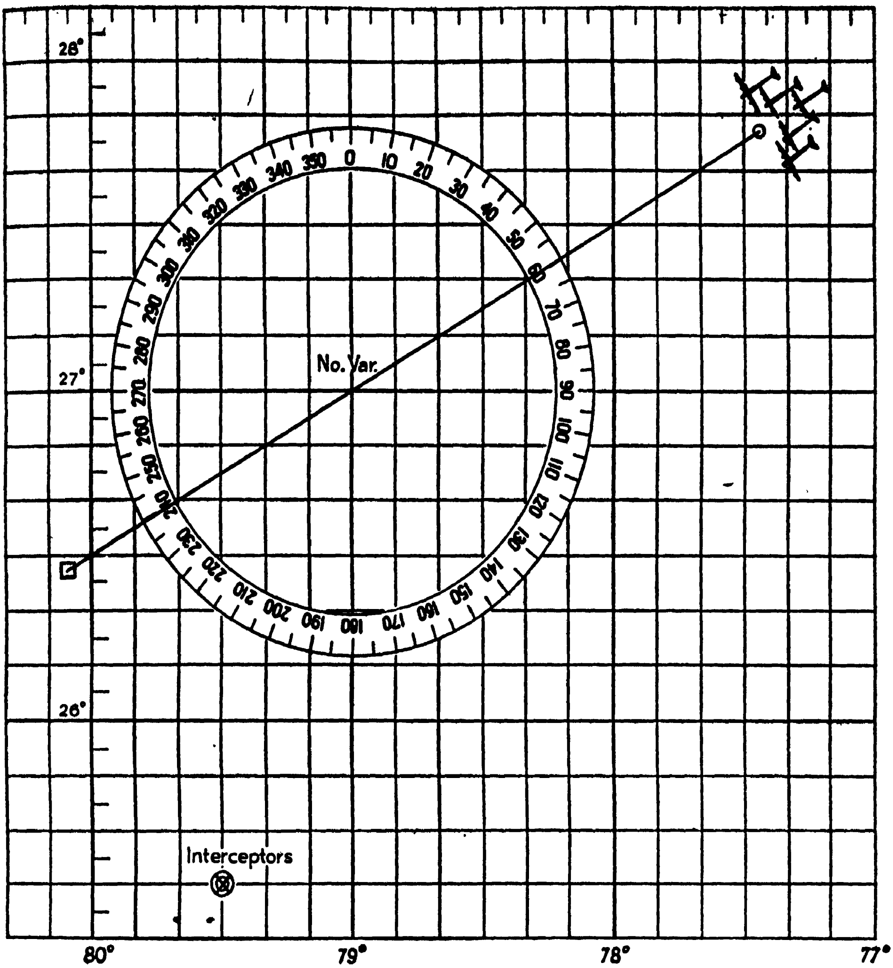


Fig. 221.—Problem 5.

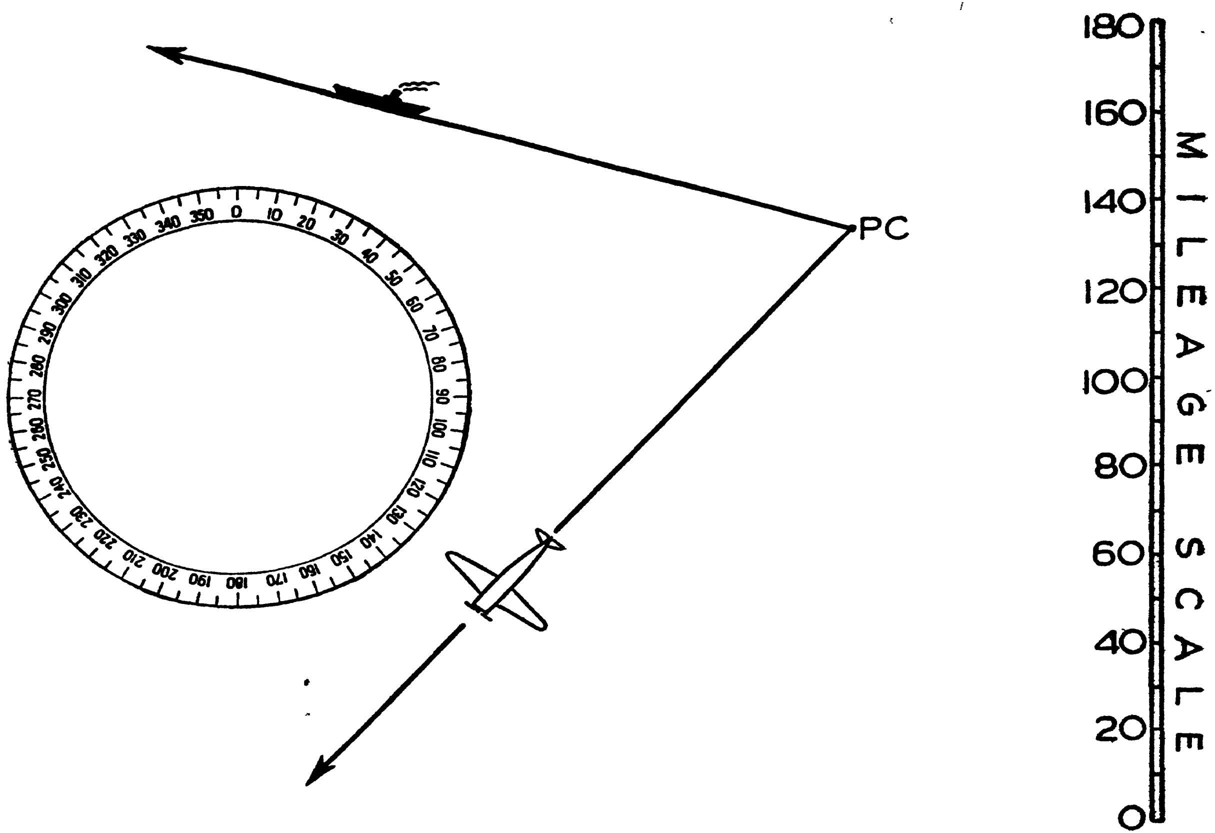


FIG. 226.—Problem 2.

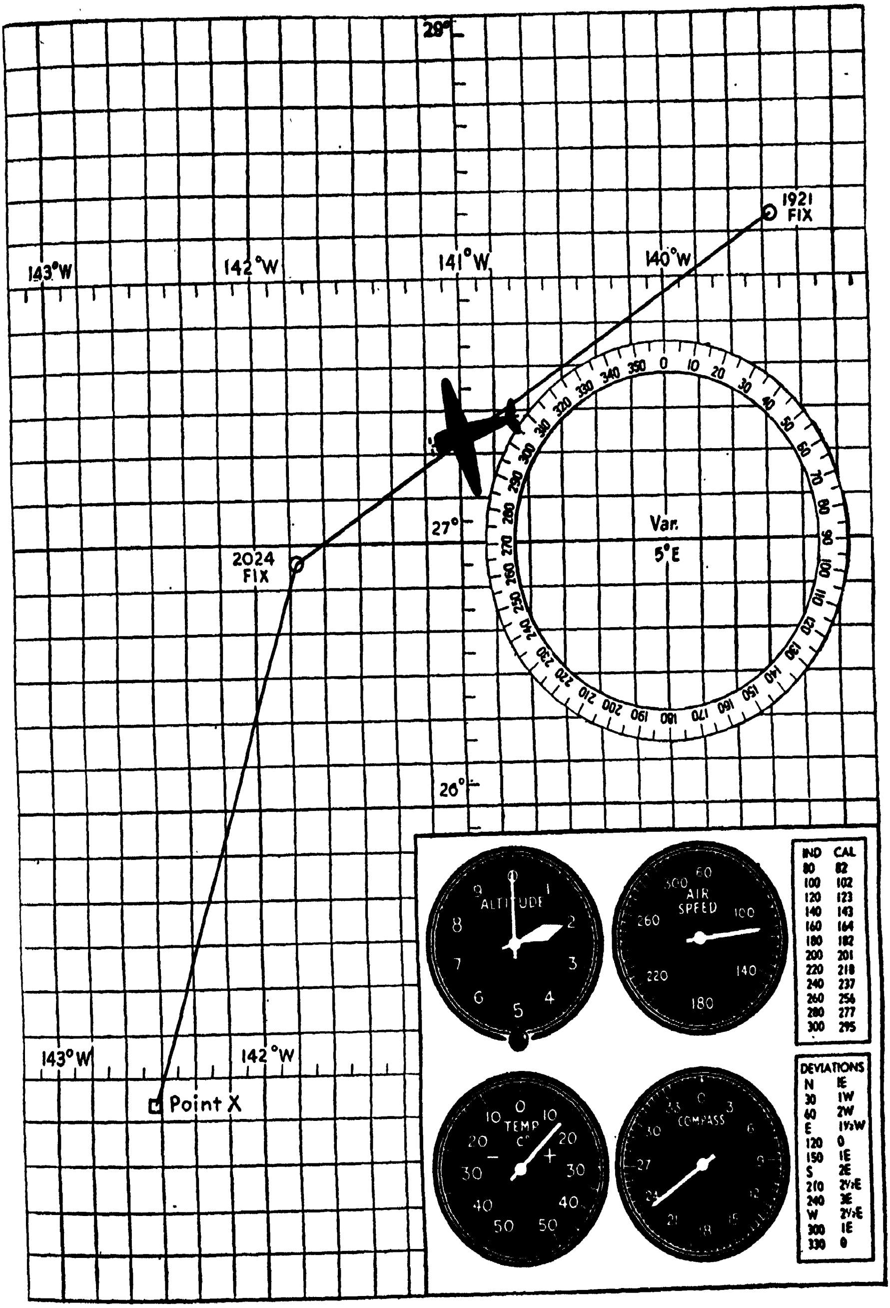


Fig. 212.—Problem 11.

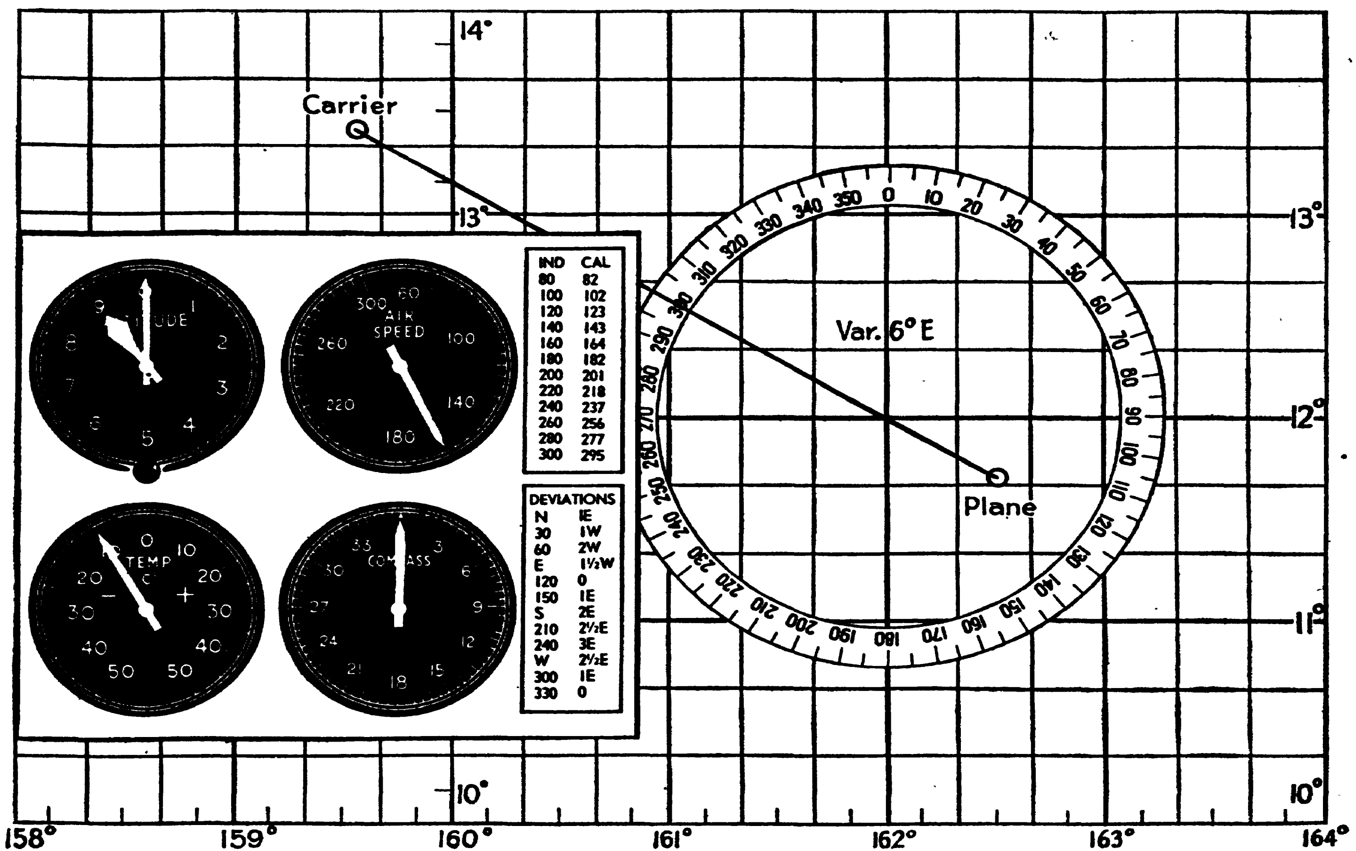


Fig. 218.—Problem 2.

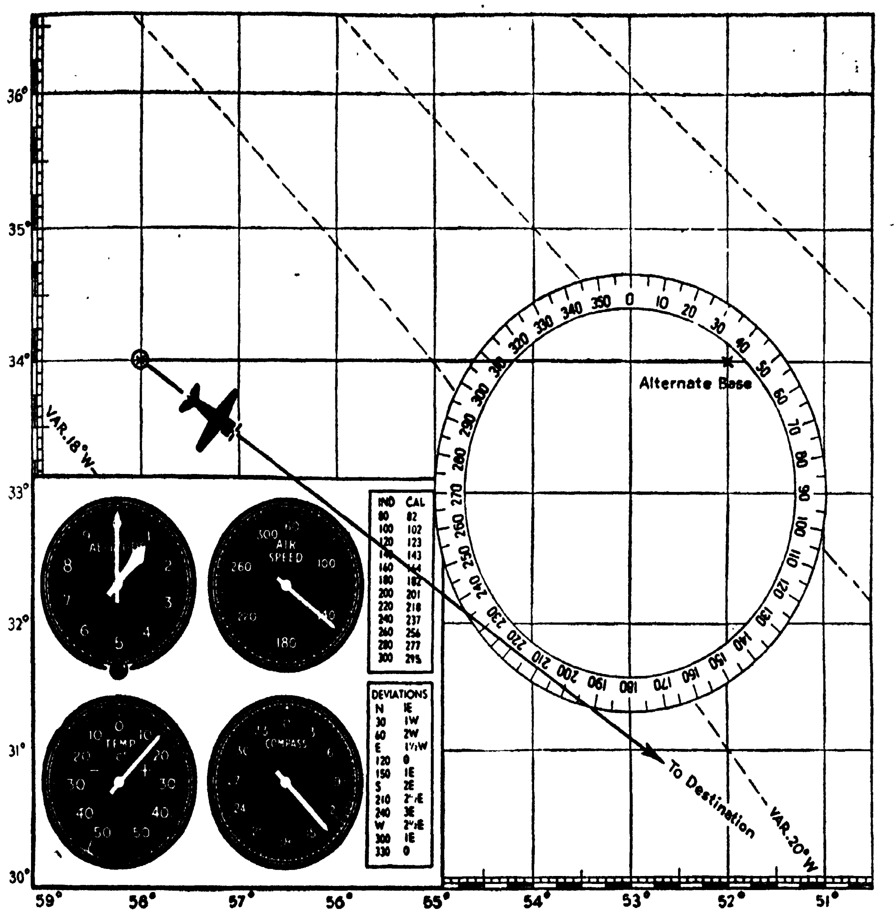


FIG. 231.—Problem 3.

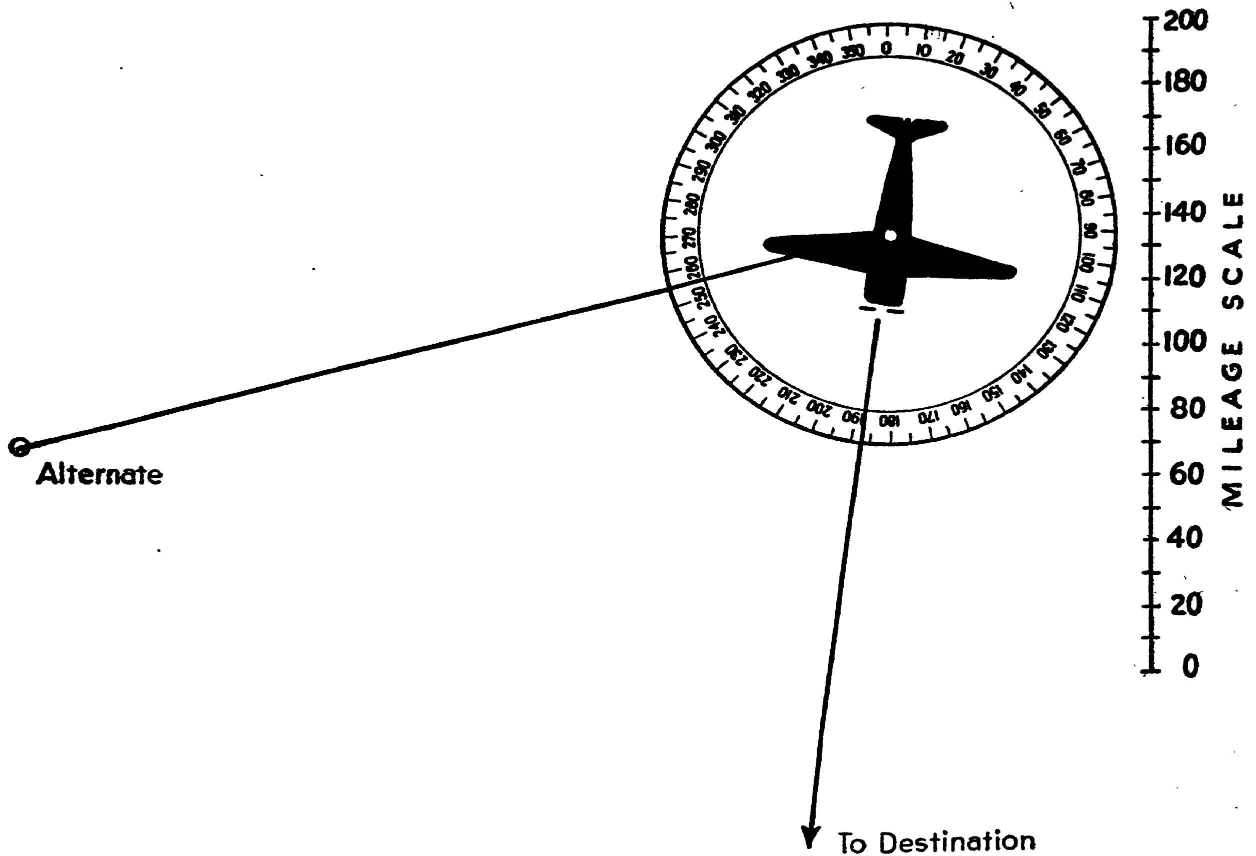


Fig. 232.—Problem 4.

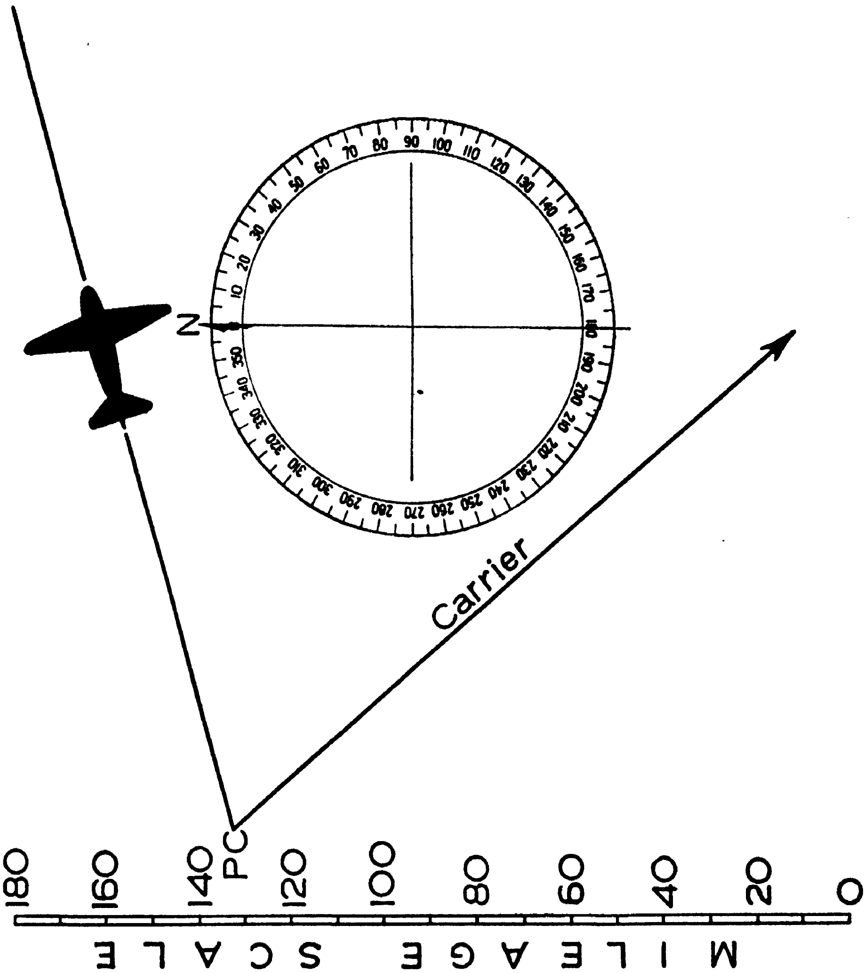


Fig. 227.—Problem 3.

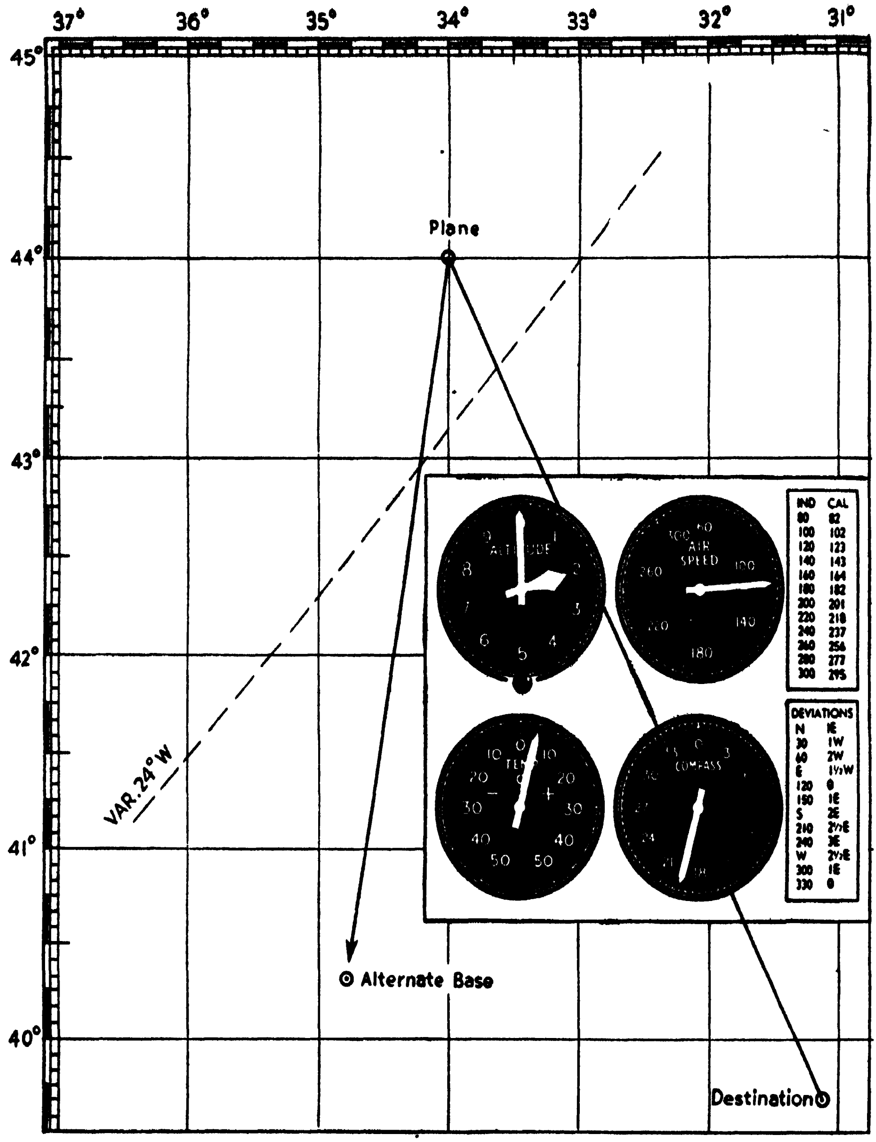


Fig. 230.—Problem 2.

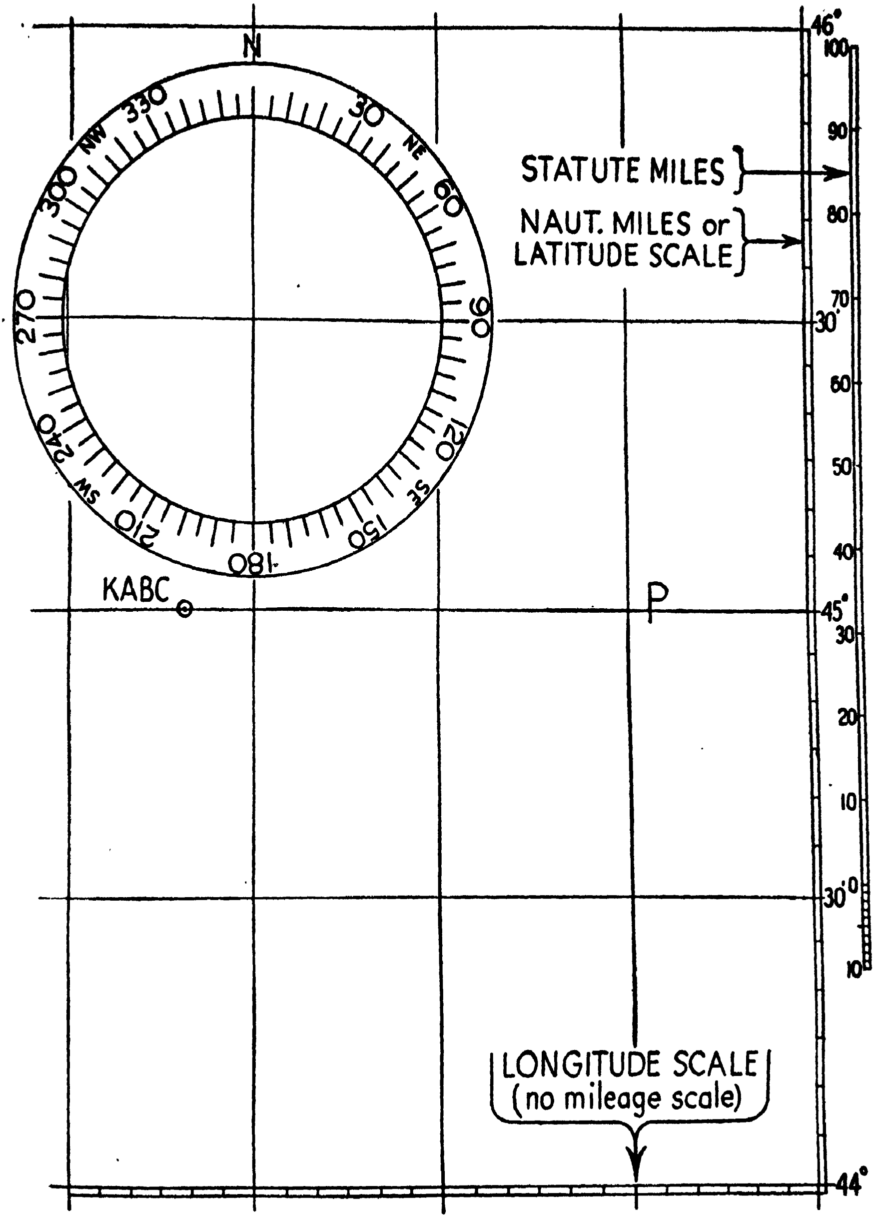


FIG. 187.—Problem 2.

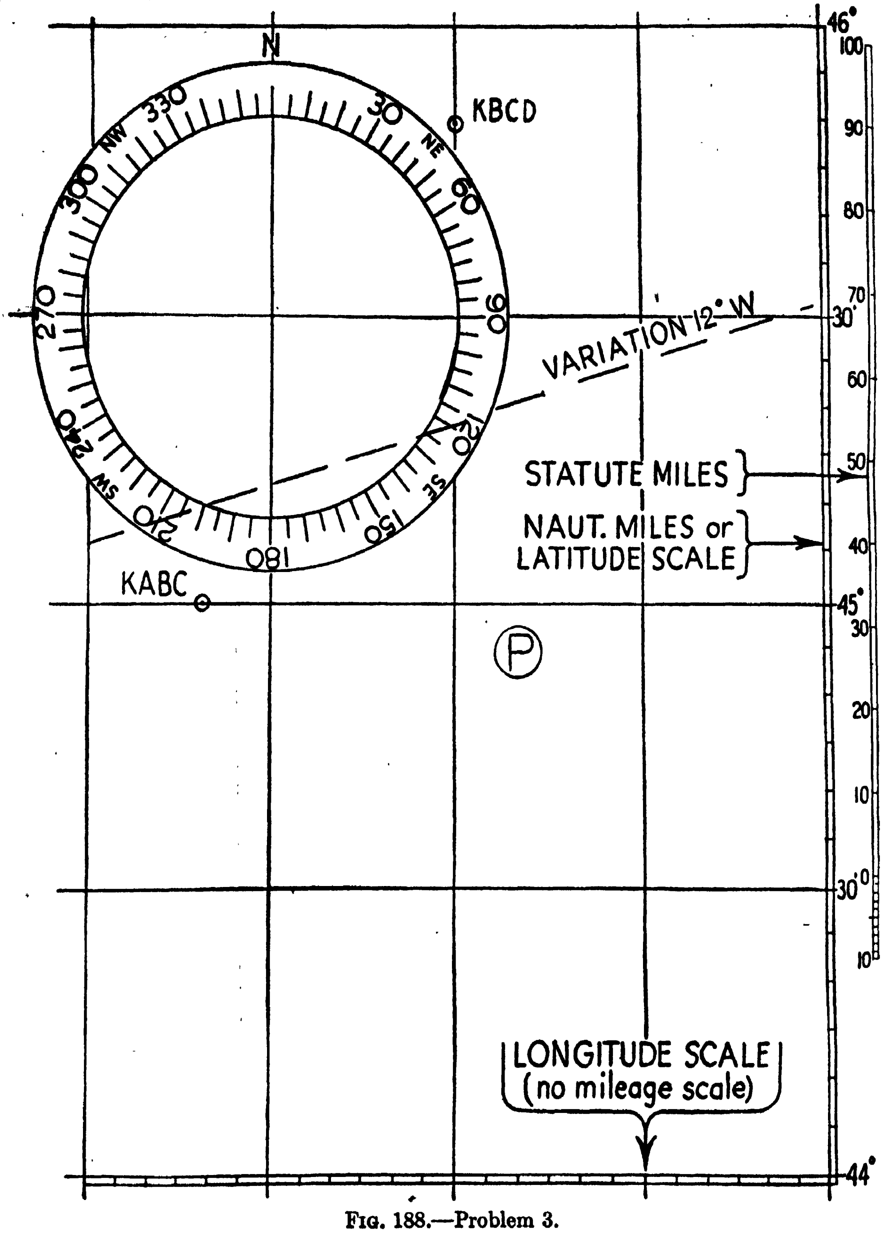


Fig. 188.—Problem 3.

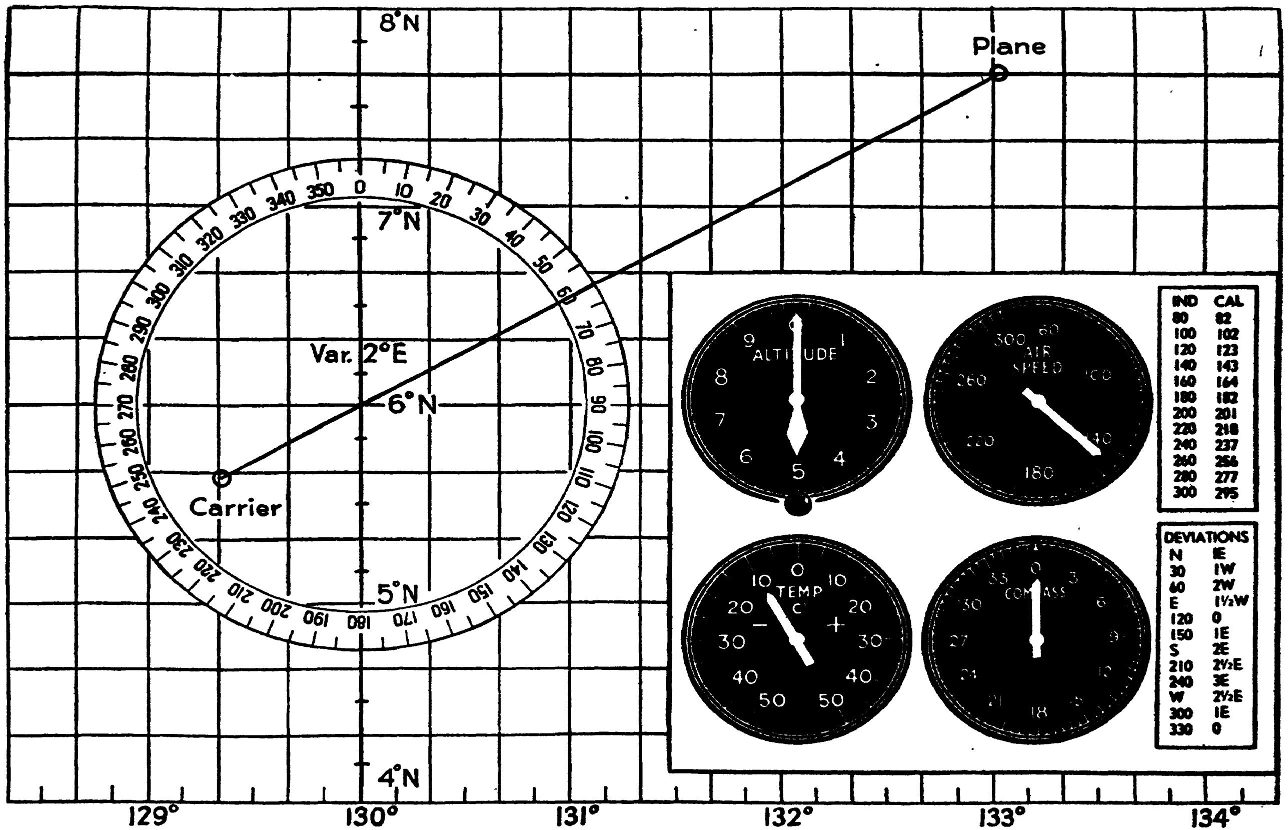


FIG. 219.—Problem 3.

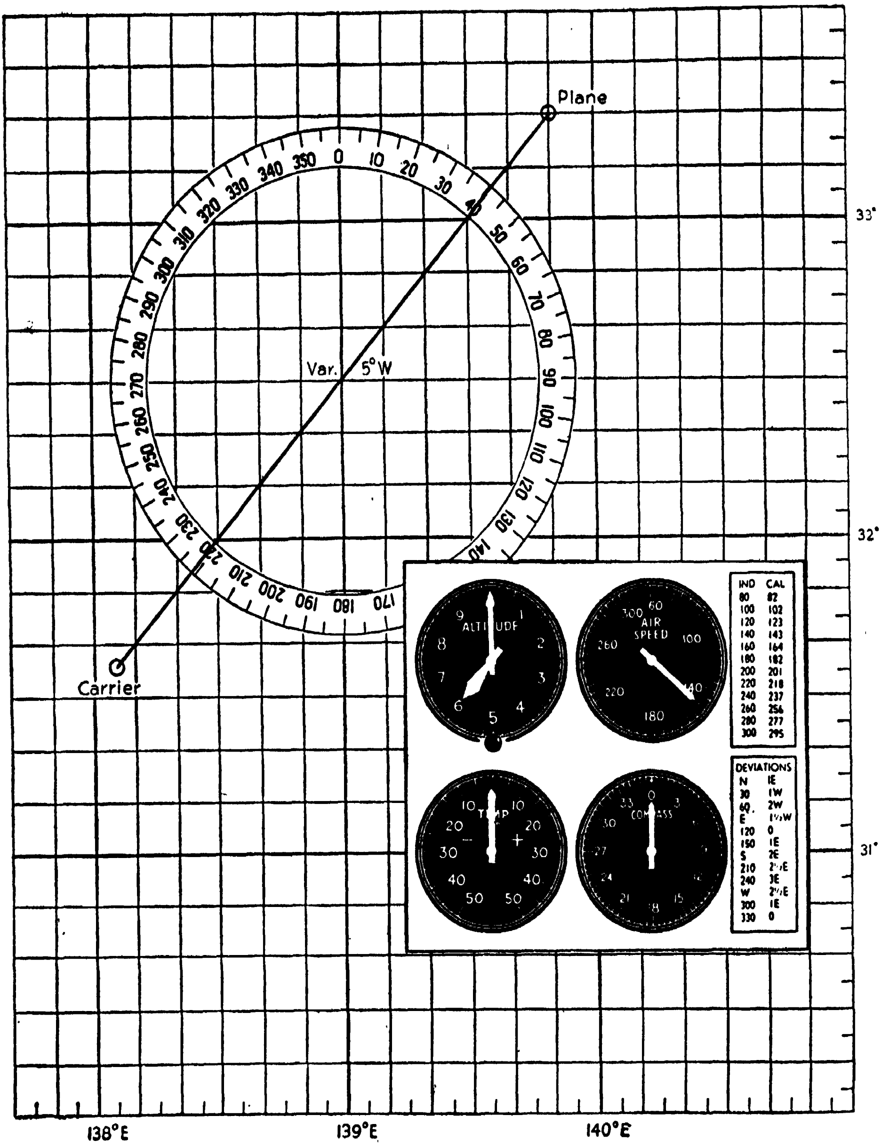


Fig. 220.—Problem 4.

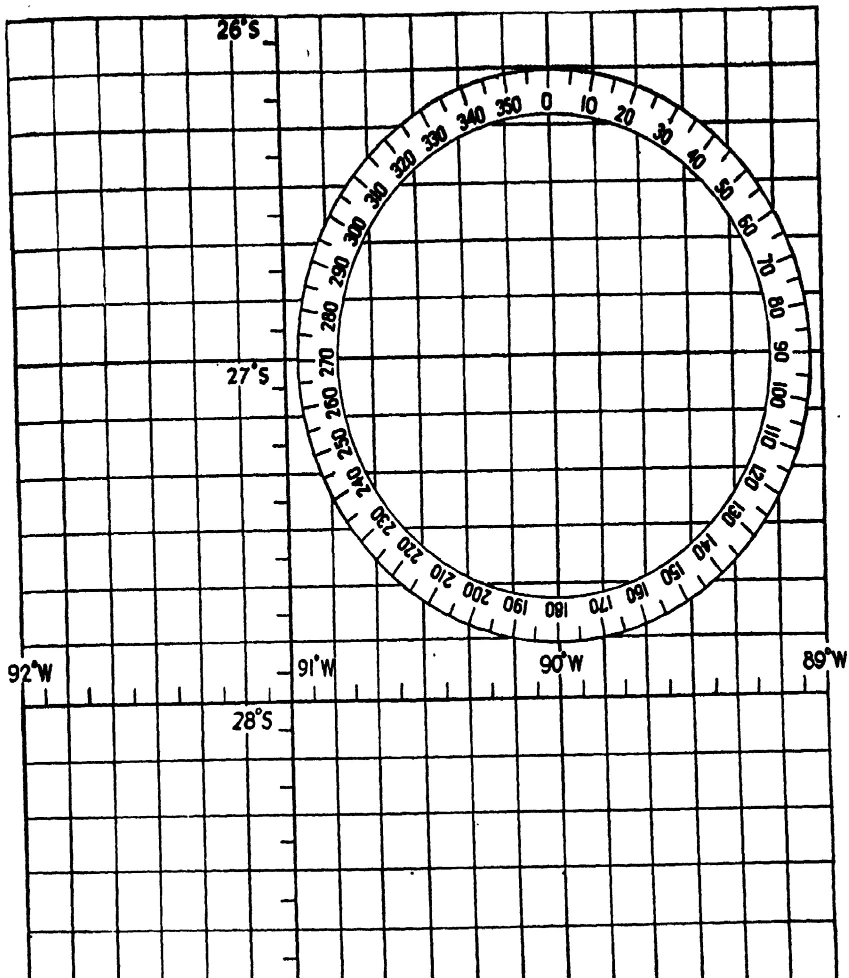


FIG. 265.—Problems 4 and 5.

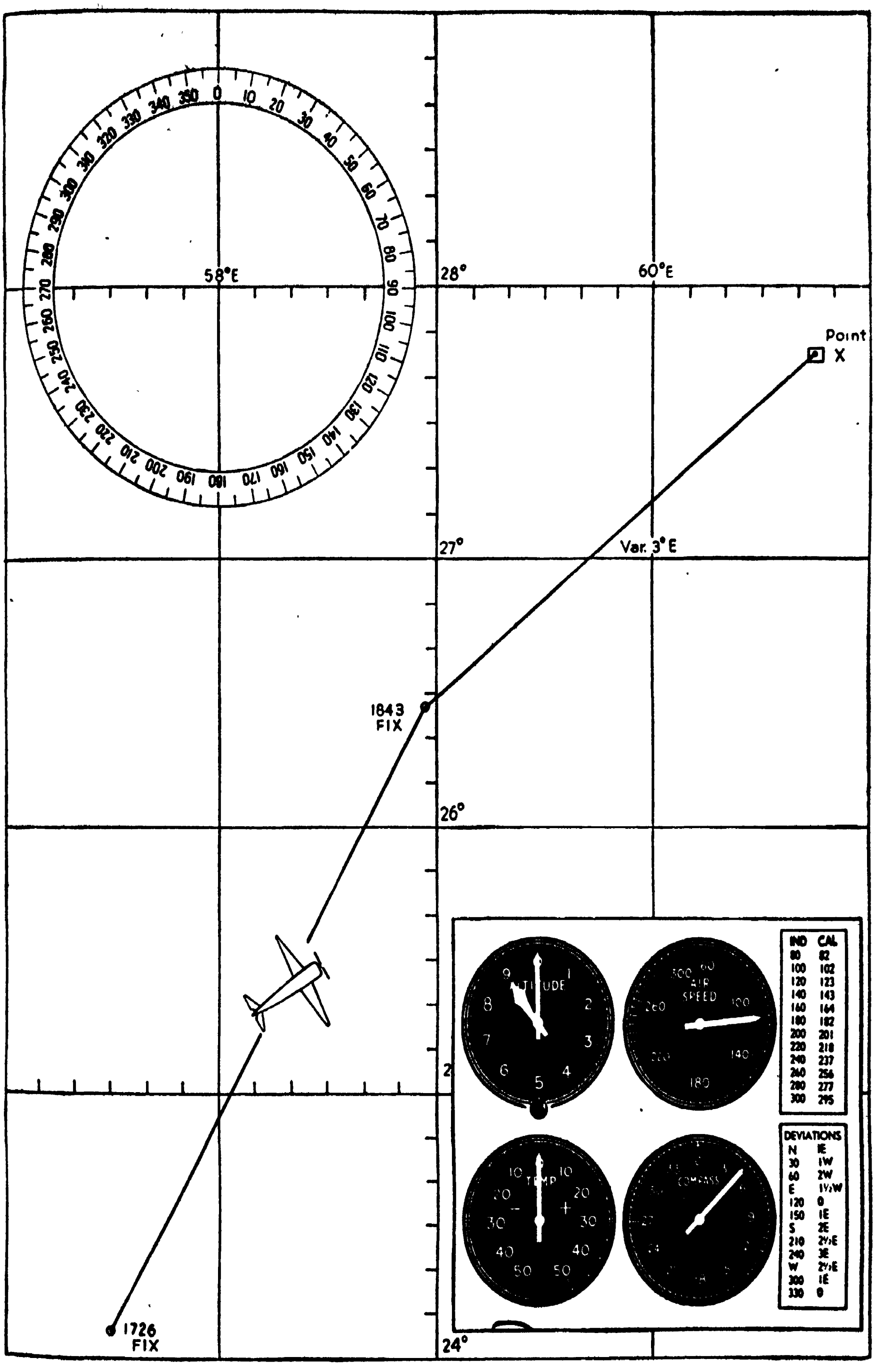


FIG. 210.—Problem 11.

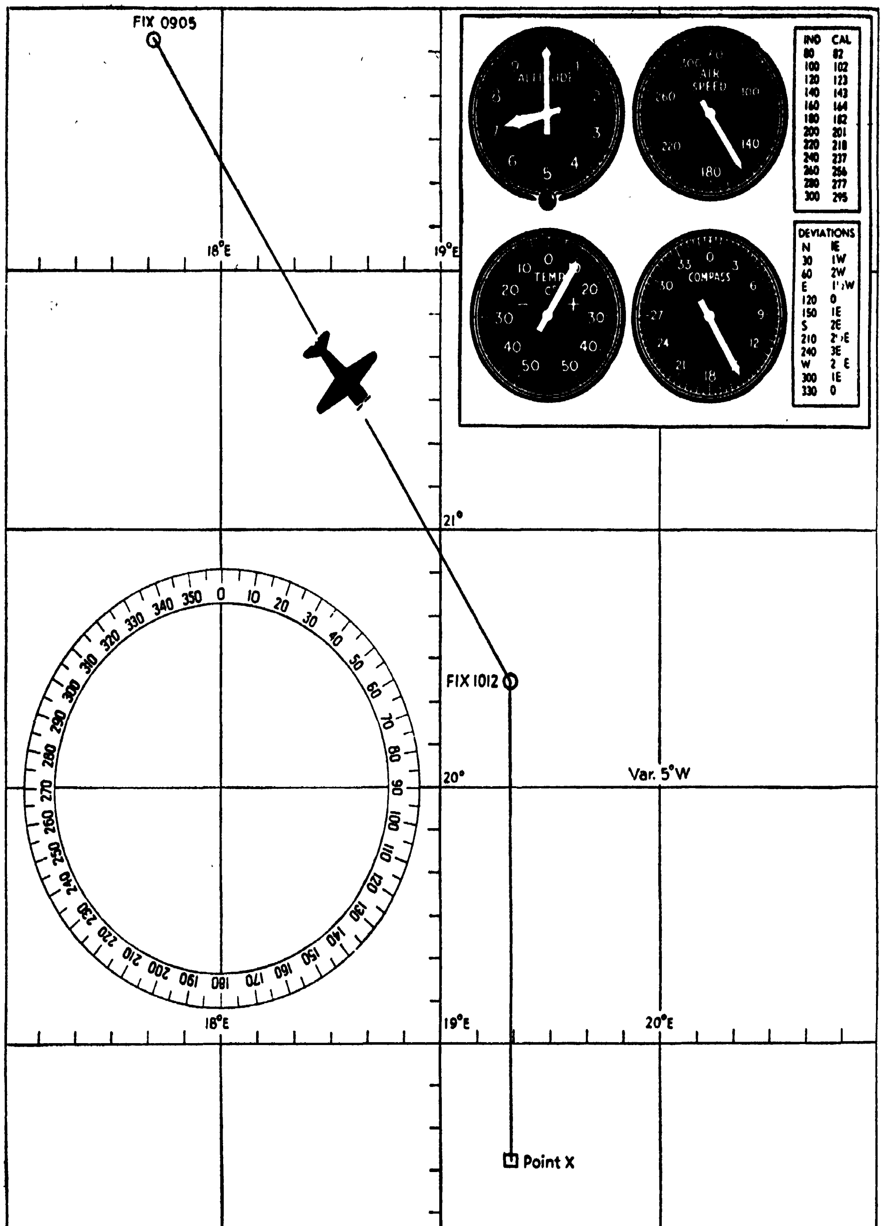


Fig. 211.—Problem 11.

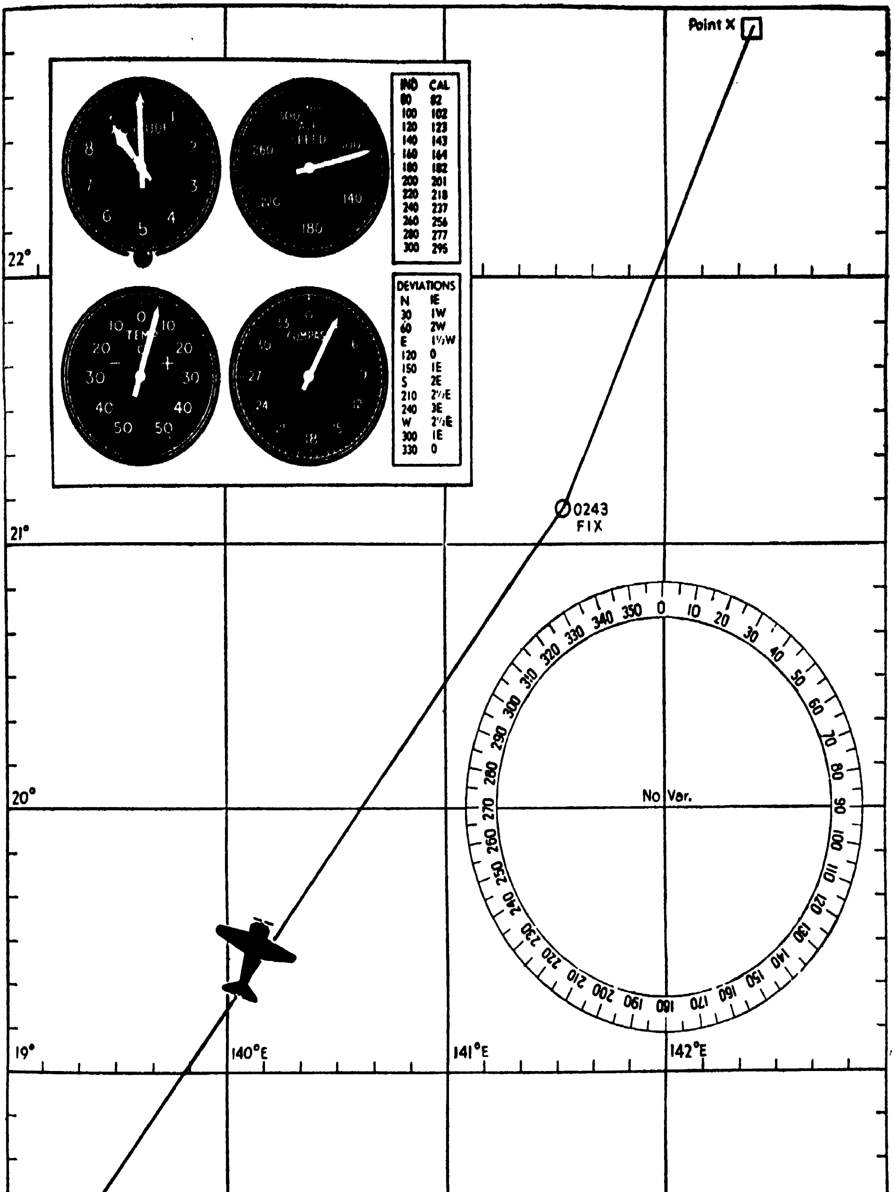


Fig. 208.—Problem 11.

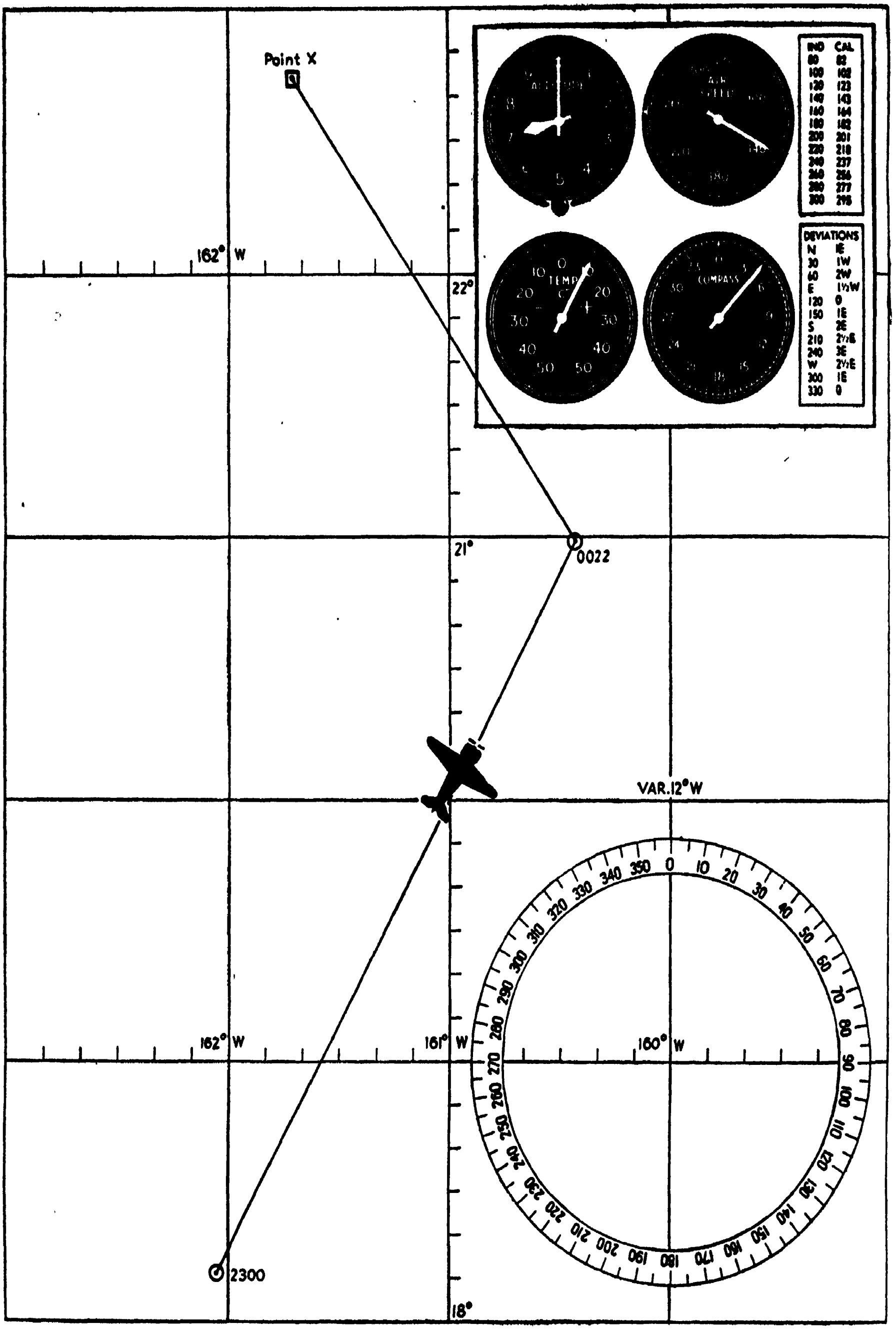
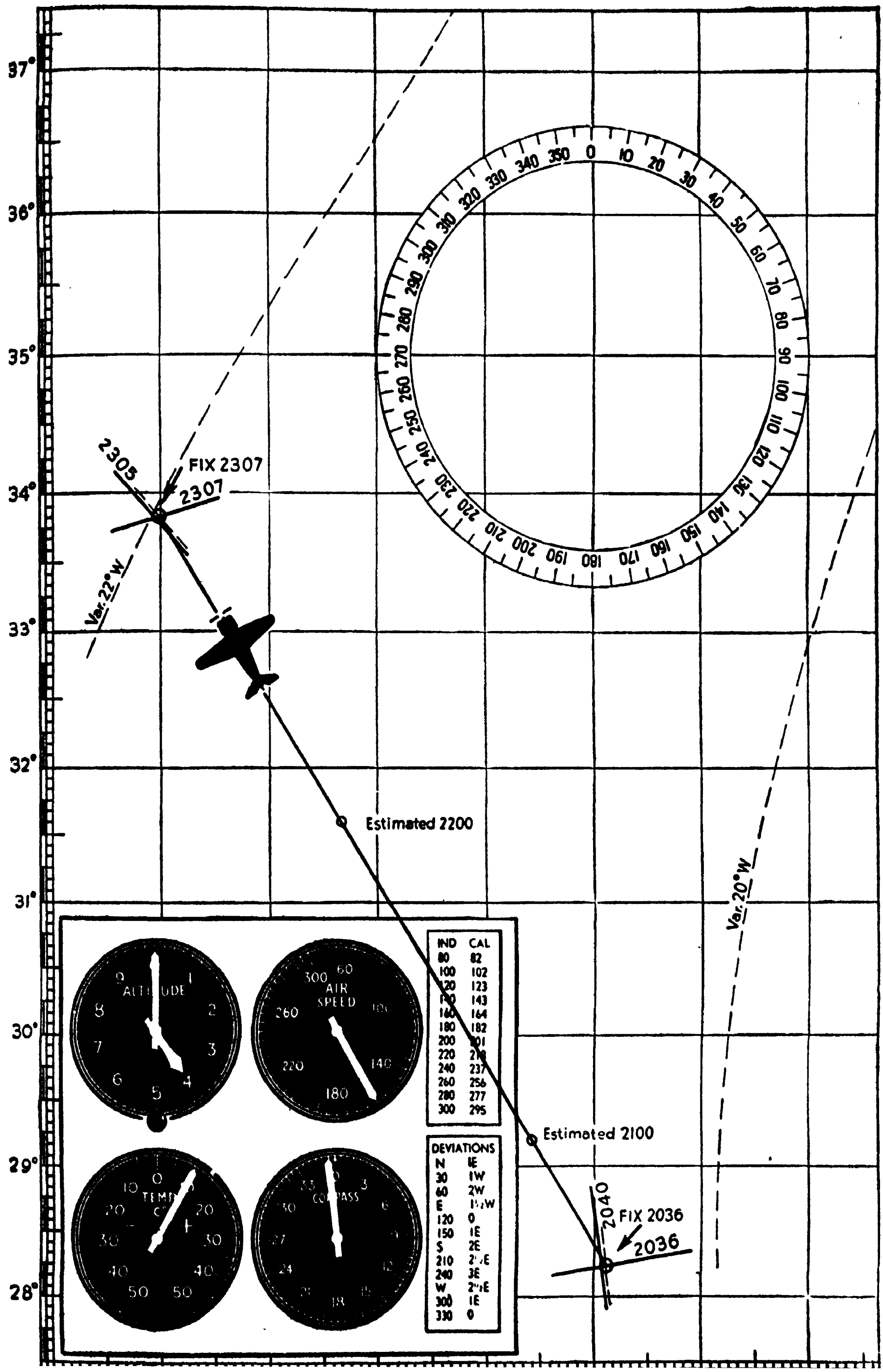


Fig. 209.—Problem 11.


37°
36°
35°
34°
33°
32°
31°
30°
29°
28°
FIX 2307
2305
2307
Var. 22°W
Estimated 2200
Estimated 2100
2040
FIX 2036
2036
Var. 20°W
ALTITUDE
AIR SPEED
TEMP C
COMPASS
IND CAL
80 82
100 102
120 123
160 164
180 182
240 237
260 256
280 277
300 295
DEVIATIONS
N 1E
30 1W
60 2W
E 1½W
120 0
150 1E
S 2E
210 2½E
240 3E
W 2½E
300 1E
330 0

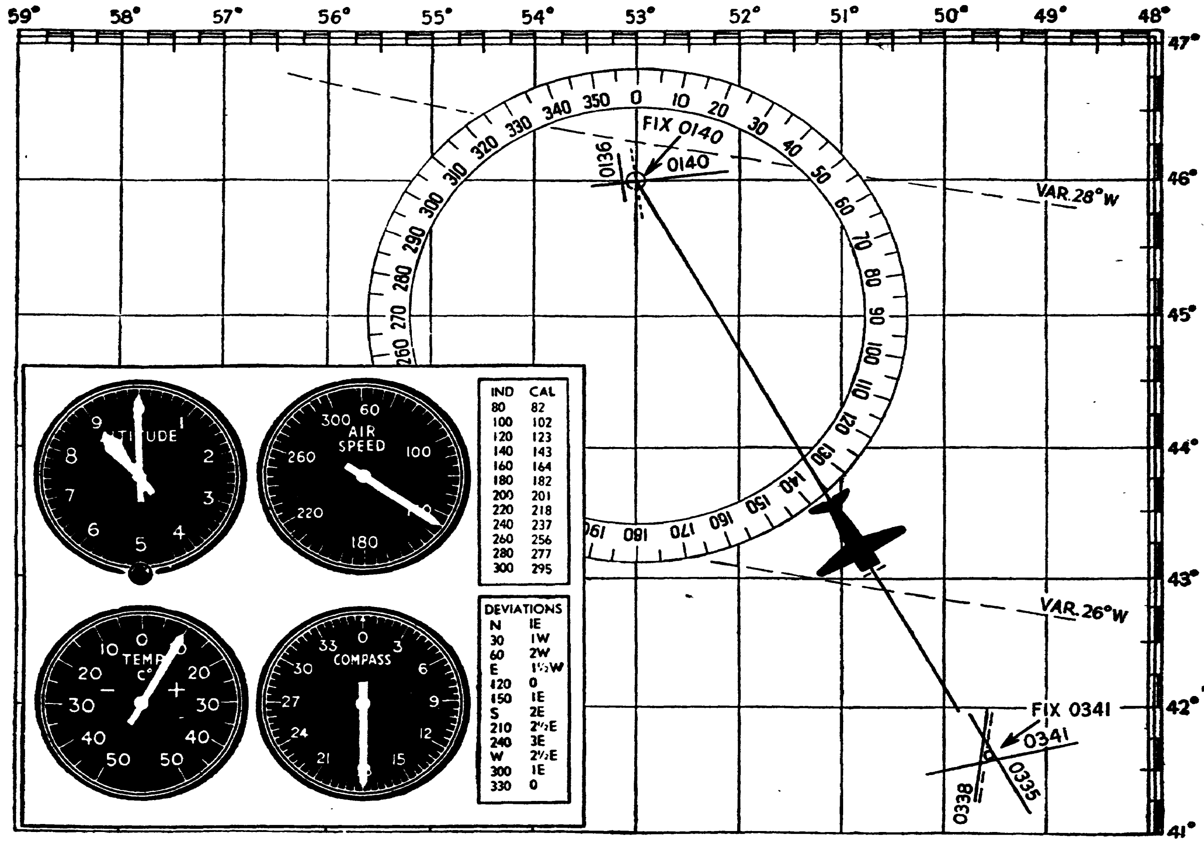


FIG. 203.—Problem 10.

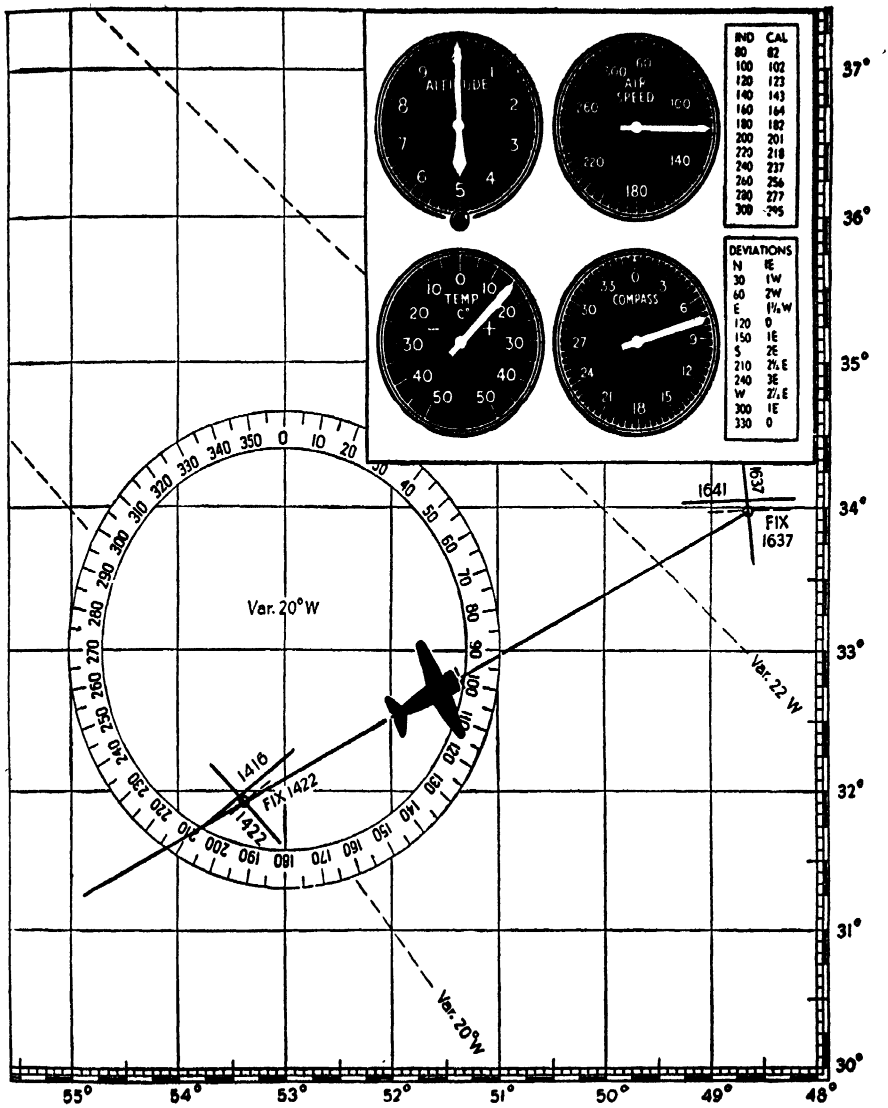


FIG. 204.—Problem 10.

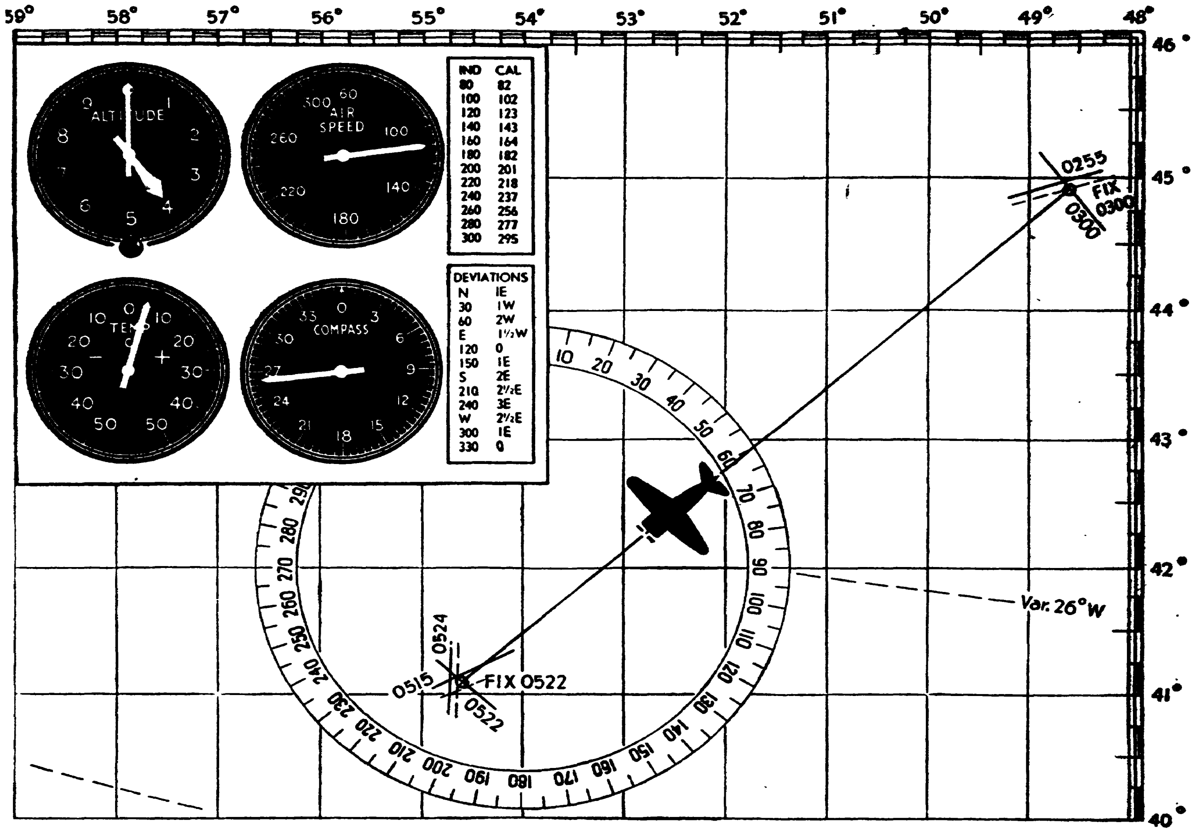


FIG. 205.—Problem 10.

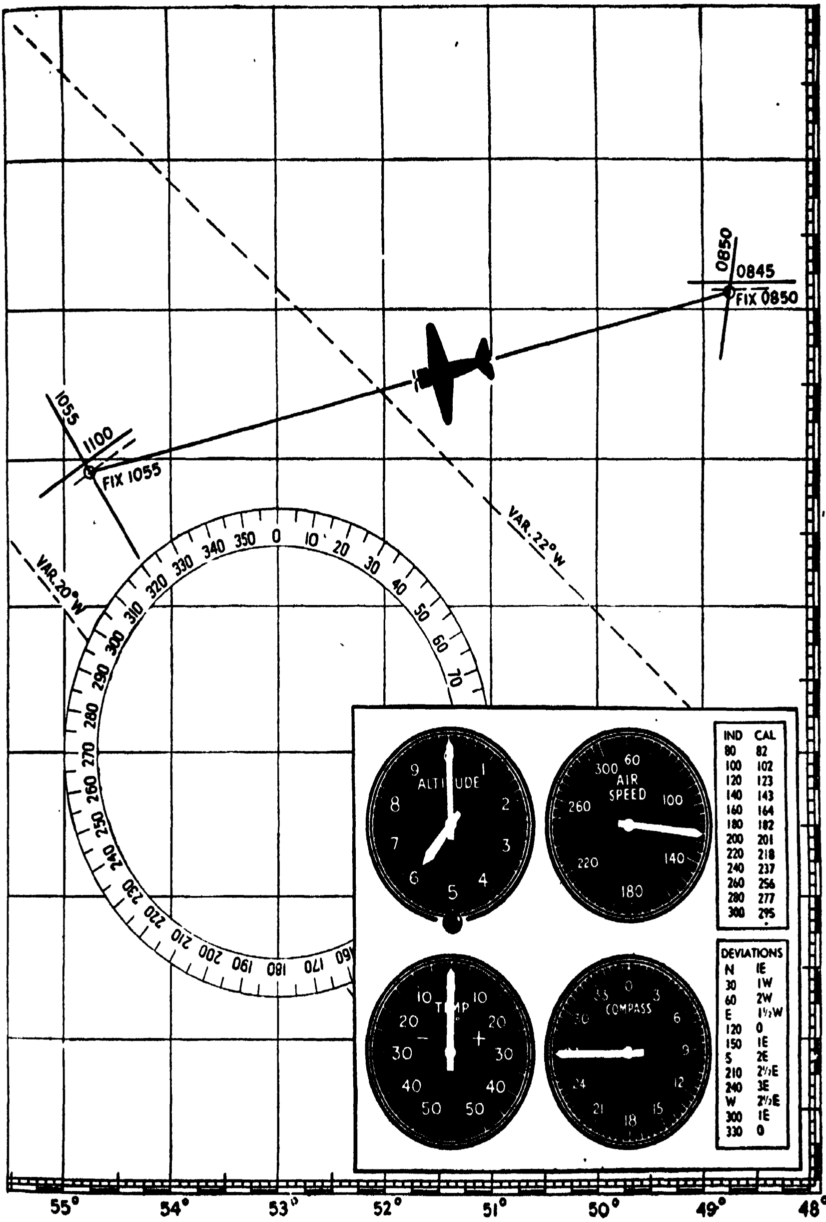


FIG. 206.—Problem 10.

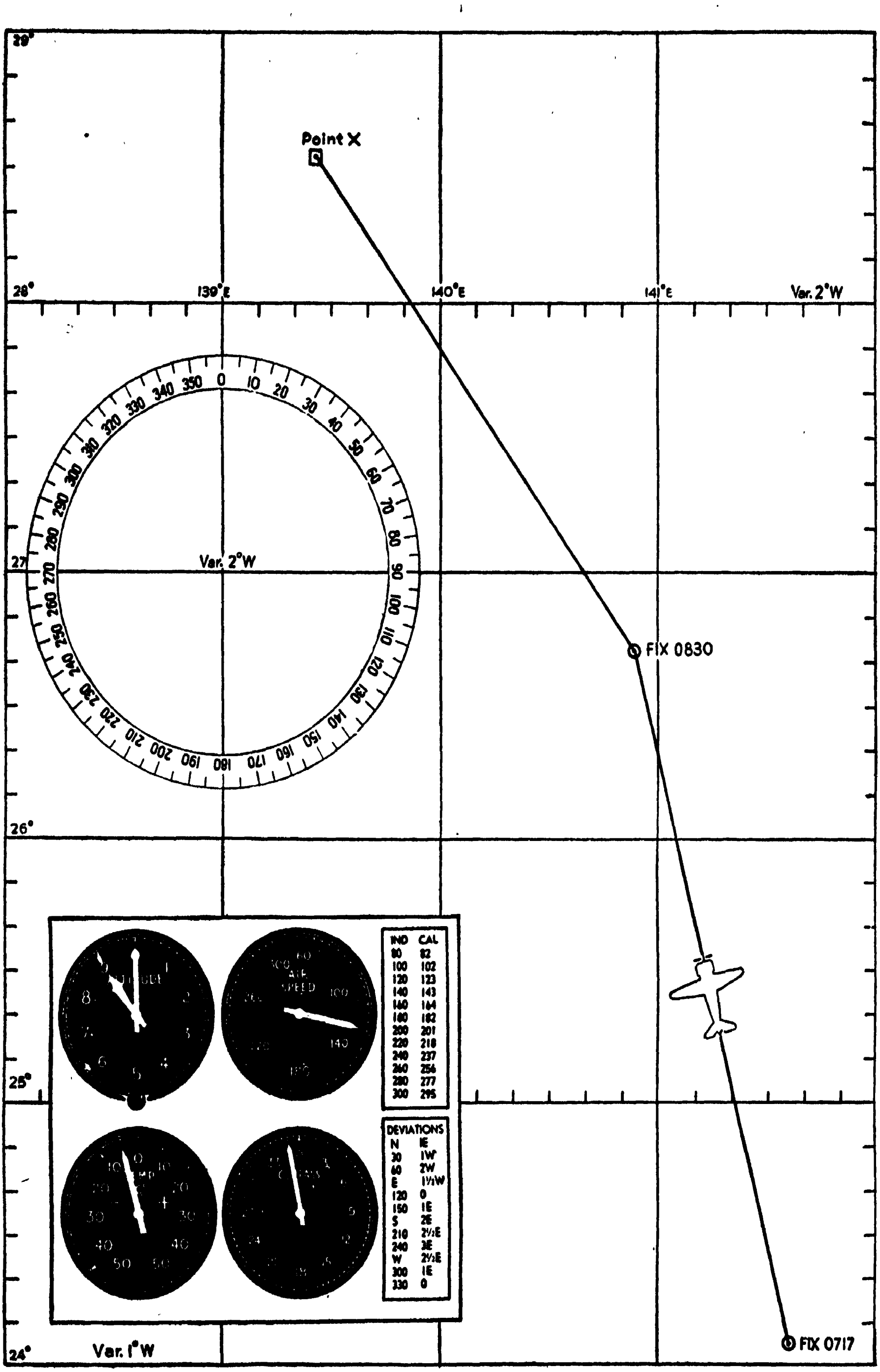


FIG. 207.—Problem 11.

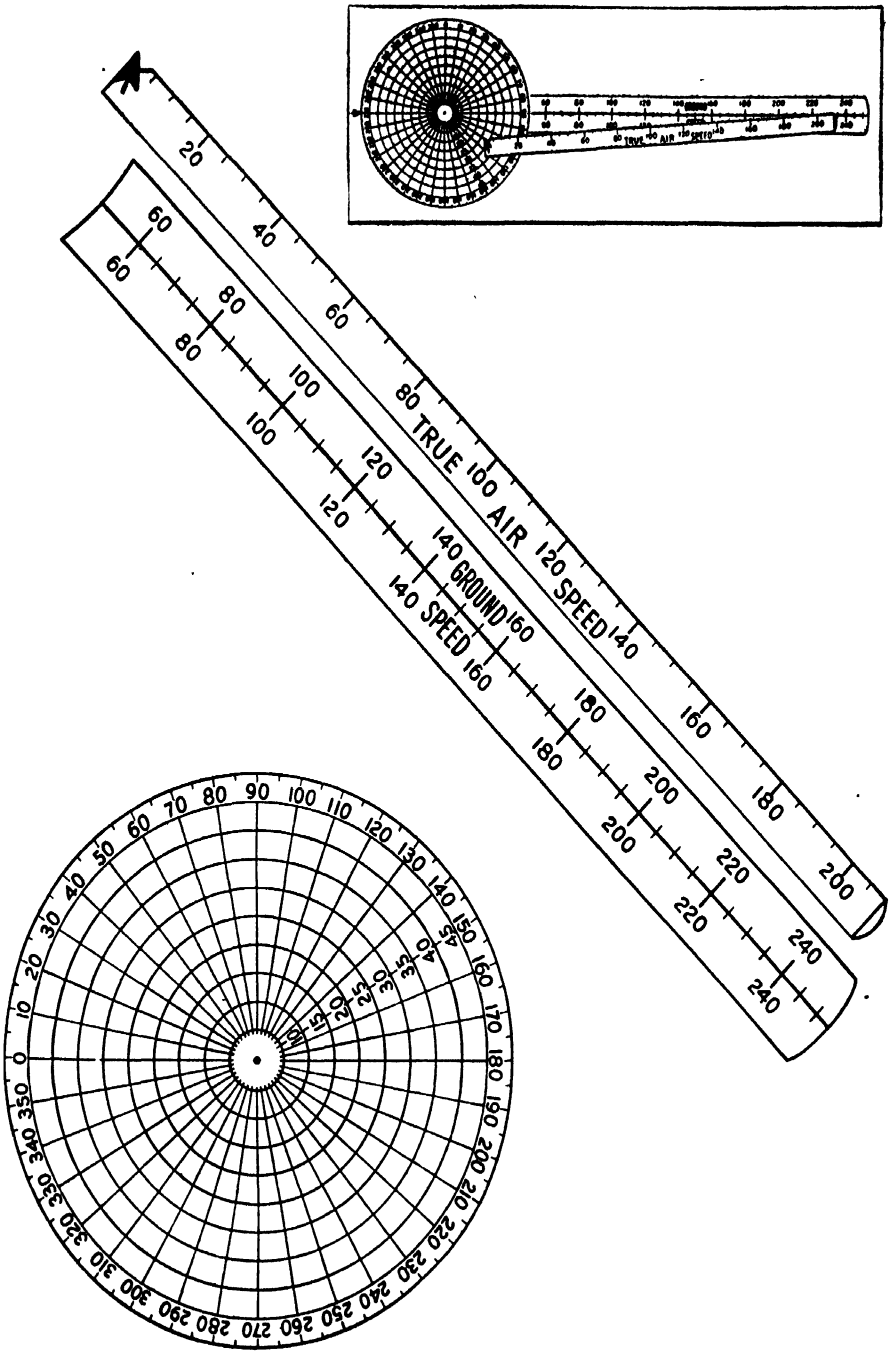
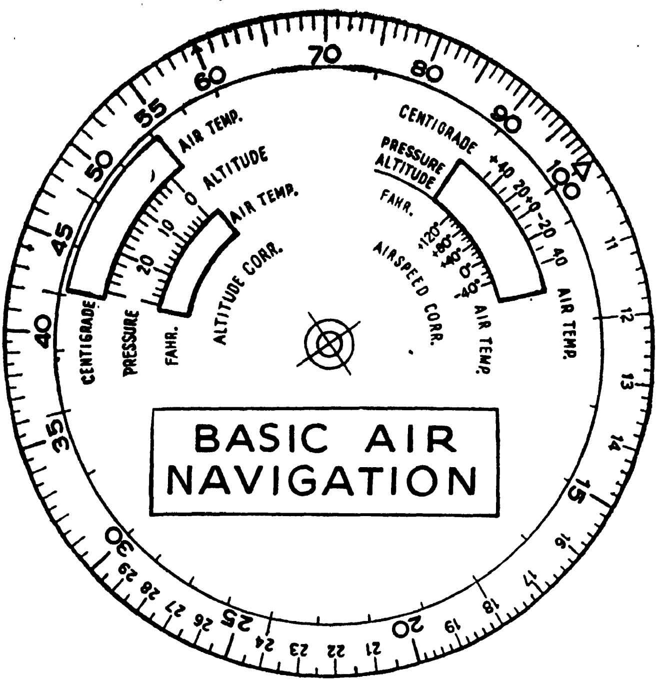
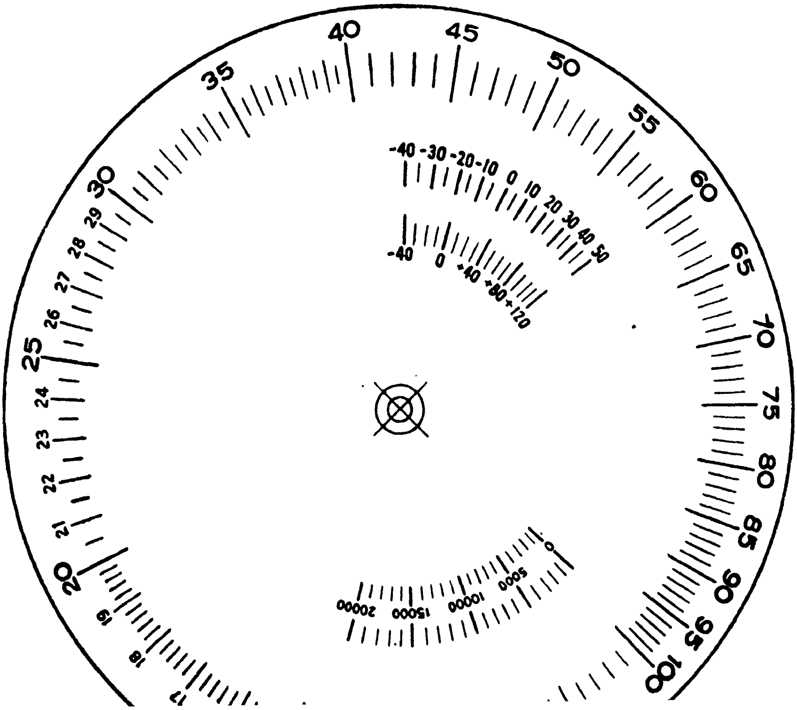


Fig. 31.—Cutout model of computer and assembly sketch.



AIR TEMP.
ALTITUDE
AIR TEMP.
ALTITUDE CORR.
CENTIGRADE
PRESSURE
FAHR.
CENTIGRADE
PRESSURE ALTITUDE
FAHR.
AIRSPEED CORR.
AIR TEMP.
AIR TEMP.
BASIC AIR NAVIGATION



From an altitude of 5,000 ft. the first of these drift bombs (*A*) appears as a white silver-dollar patch on the surface of a glassy sea; if the sea is agitated moderately, it cannot be seen at all. The bronze powder bomb (*C*) is a little more readily distinguished on the surface, but the student should not expect to see a large white or yellow patch in either case. A water light (not shown) consists of a tin can with a soft lead patch on either end, both of which must be removed before the can is thrown overboard in order that water may enter and ignite the chemical within. On a dark cloudless night the author has been able to see the light from such a unit for approximately 20 miles. Even with high-speed aircraft, more

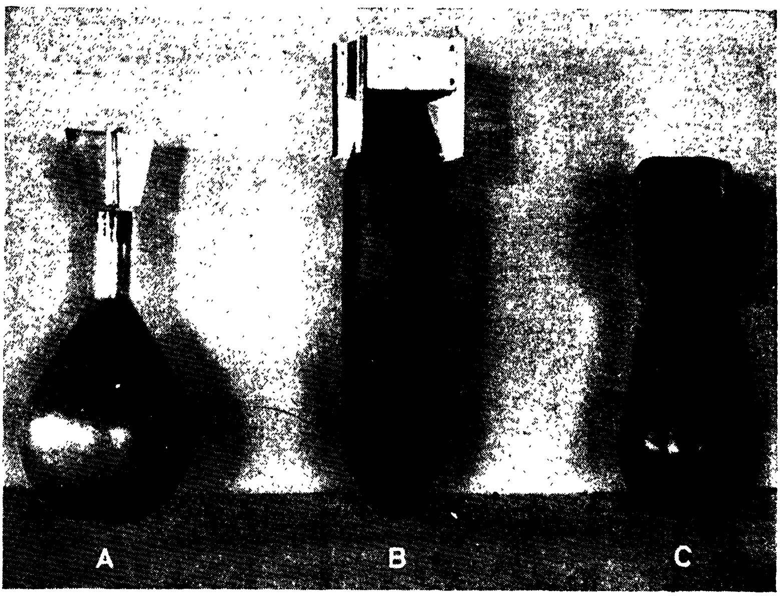


FIG. 129.—Bombs used for drift observations.

than ample time is generally available to determine an accurate drift. The water flare (*B*) gives off an intense white light (much brighter than that of the water light), and on a hazy night it has distinct advantages over the former in point of visibility. It burns out, however, in 3 to 4 min., and the navigator must be on the alert to commence taking the drift observation as soon as the light flares. It must be borne in mind that pilot cooperation at the controls is essential during these observations, since a change in heading results in an erroneous observed drift.

It not infrequently happens that a water light, after having been thrown overboard into a wide clear space below the plane, apparently fails to ignite on hitting the surface. This is especially true when the water light is thrown overboard from a high altitude. Scattered clouds

below the plane appear to pack together in perspective when astern of the plane and obscure the flare.

Cross-trail Error.—In general, the navigator may expect to experience more drift than that shown by water-light or drift-bomb observations. After having been thrown overboard, the water light drifts sideways with the plane and does not become stationary until it has reached the surface (see Fig. 130).

A in Fig. 130 illustrates what happens when a water light is thrown overboard at low altitude. It comes to rest on the surface almost immediately and thereafter fails to partake of the motion of the wind, which continues to act on the plane. Since the plane continues to drift sideways from its former position immediately above the light, an

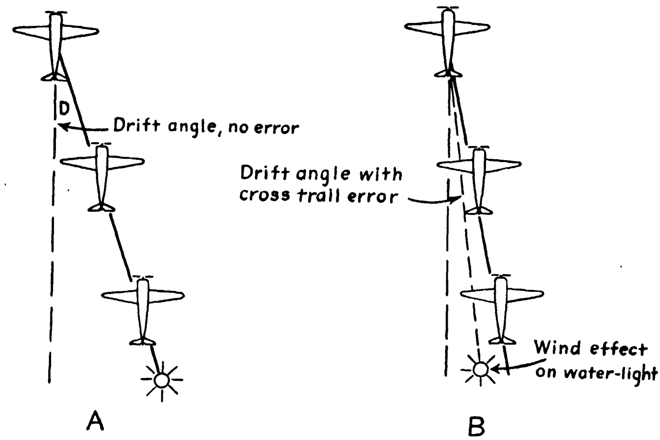


FIG. 130.—Cross wind—cross-trail error.

accurate drift observation may be made. The correct drift angle is labeled *D*.

B illustrates what happens when a water light or bomb is thrown overboard at high altitude. If the wind direction and velocity are the same in the lower levels through which it descends, it continues to drift sideways as much as the plane until it becomes stationary on the surface.

From an altitude of 10,000 ft. a full minute elapses before the water light reaches the surface, and during this interval it may drift sideways a full mile. It becomes stationary on the surface but does not mark a spot over which the plane passed. Hence a measurement of the angle of drift from this illuminated spot would result in material error.

Of course, radical wind shifts below the plane may neutralize each other, and the water light may come to rest directly beneath a point over which the plane passed. However, there is no way of knowing that this actually did occur, and drifts obtained in this manner should be weighed carefully.

The difference between the correct drift and that obtained from an object thrown overboard at high altitudes is known as **cross-trail error.** The author has experienced cross-trail errors of 5°, and although this is a little unusual greater cross-trail errors can occur. Large cross-trail errors can be materially reduced by waiting as long as possible before reading the drift indication. For example, at 180 m.p.h., drift obtained from an altitude of 10,000 ft. on a water light may read 5° instead of a correct value of 10° when taken 1 min. after the water light first flares in the sea. If the observation for drift can be postponed 3 min. more, a drift of 8° instead of 10° may possibly be observed.

On long flights during which the air speed cannot be increased owing to excessive fuel consumption, the navigator can do very little to improve the ground speed. It is his responsibility, however, to make certain

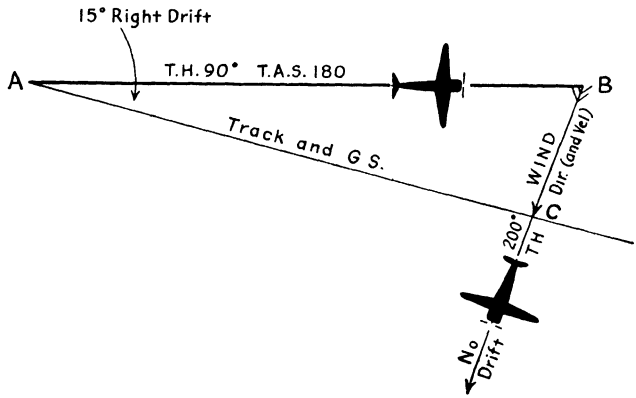


FIG. 131.—Graphic solution for wind with two drift observations—special case.

that such ground speed as is made good is made good toward the destination. Under this condition, close observation of the drift is the only means by which the navigator can contribute to the success of the flight.

Determination of Wind Direction and Velocity by Means of Multiple-drift Observations.—In Chap. I during the discussion of the various practical solutions of the triangle of velocities, it was stated that the winds aloft could be ascertained by means of the so-called "double-drift" or "wind-star problem" (page 6). The value of such a determination was emphasized at that time. It was pointed out that knowledge of wind direction and velocity when used with the factors true heading and air speed constituted a perfect combination for the solution of track and ground speed.

Both the wind-star problem and the double-drift problem may be classified as multiple-drift problems, since the only difference between the two lies in the number of observations taken. In establishing the

wind in this manner the navigator observes the angle of drift on two or more widely separated headings, and from a graphical analysis of these drifts he ascertains the wind.

Let us assume that a plane makes a true air speed of 180 m.p.h. on a 90° true heading but drifts 15° right. Obviously, the wind is blowing from the left, *i.e.*, from a general northerly direction. The navigator may request the pilot to turn slowly south and steady the aircraft at frequent intervals. Eventually, a heading will be reached on which no drift will occur. The plane will then be heading directly down wind.

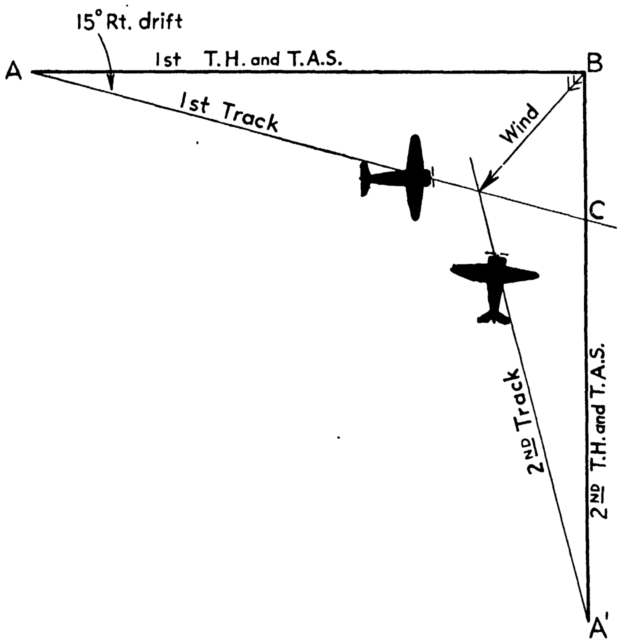


FIG. 132.—Graphic solution for wind by means of two drift observations.

For the purpose of illustration (see Fig. 131), let us assume that zero drift occurred on a true heading of 200°. This illustrates a specific problem of determining wind direction and velocity in flight by observing the drift on two different headings. In this problem, the first drift noted was 15° right; on the second heading, zero drift was observed.

It is unnecessary, however, to swing the ship until zero drift is observed; it is generally sufficient to obtain drifts on two widely separated headings. Figure 132 shows the graphic solution of this problem. In this case the plane headed 90° true and observed 15° right drift just as it did in the first problem. In the second trial the plane was headed north, and 14° left drift was observed. A line drawn between the junc-

tion of the true headings and the intersection of the tracks represents the wind velocity (on the same scale used for measuring the true air speed), and the wind direction (obviously from the left) is indicated by the direction of this short line.

If the navigator is at all concerned about the accuracy of the wind determined by this double-drift method, the drift on a third heading may be observed to check the accuracy of the first two observations. Drift, for example, could have been observed on a heading of 45° true, and on this heading if the other observations were correct a drift of

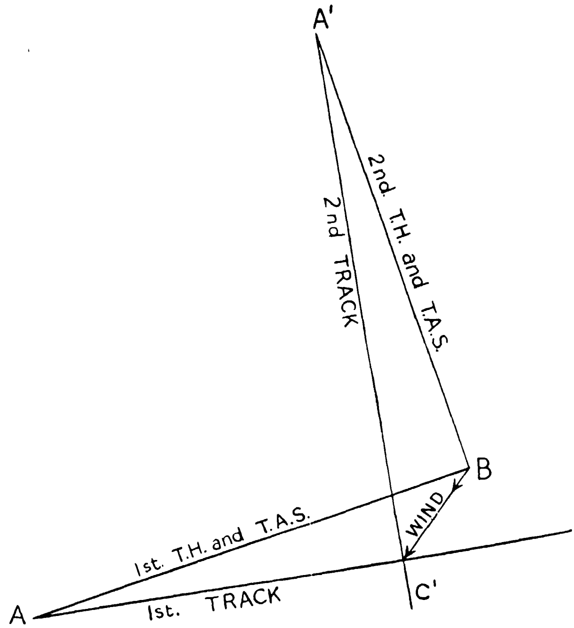


FIG. 133.—Solution of Prob. 1.

approximately 9° right should have been noted. In any event, the wind arrow is drawn from the junction of the true headings to the intersection of the tracks or to the center of the triangle formed by these tracks if they do not meet at a point. The tail of the arrow is *always* at the intersection of the headings; the barb, or point, of the arrow is *always* at the intersection of the tracks and points out the direction in which the wind is blowing.

As was stated before, two drift observations are required for the solution of the double-drift problem. If more than two drift observations are used, the diagrammatic solution begins to take on the appearance of a star; because of this, the problem is known as the *wind-star problem.* Basically, both are the same; the difference lies in the number of observa-

tions taken, and all problems of this nature may be classified as *multiple-drift problems.*

PROBLEMS

1. On a true heading of 70°, while a true air speed of 150 m.p.h. is being made, 10° right drift is observed. The navigator wishes to determine the wind direction

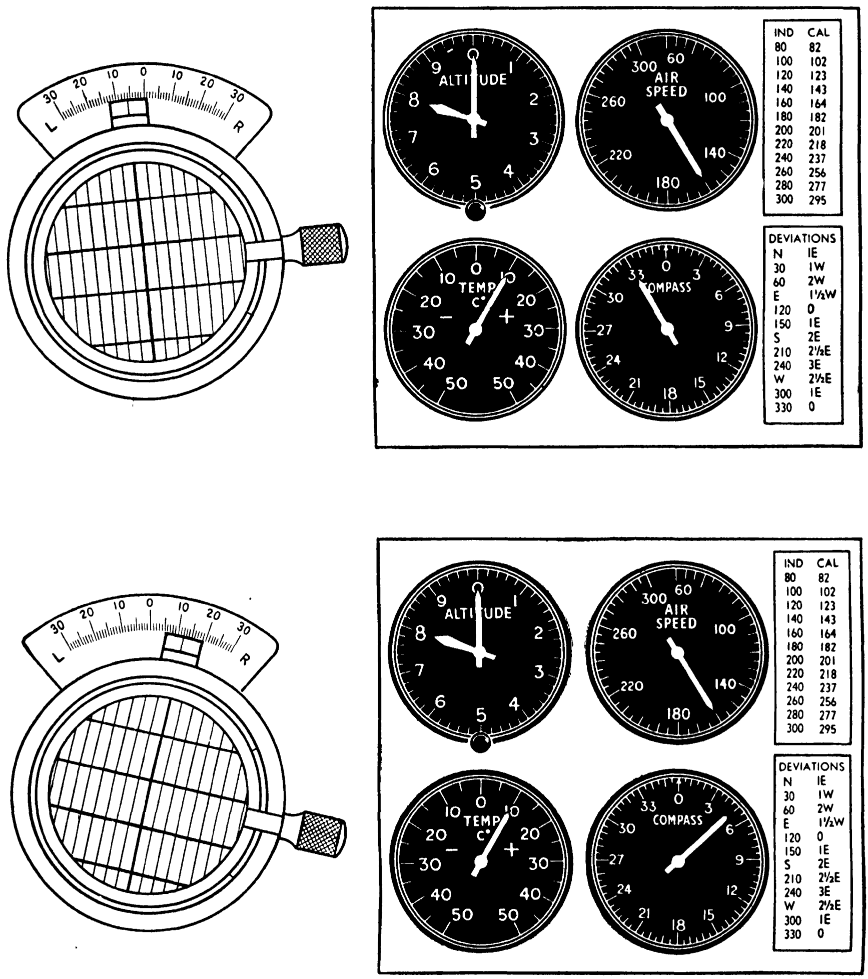


FIG. 134.—Problem 4.

and velocity and requests a change of heading 90° right. On this new heading a drift of 10° right is again observed.

Required: Determine the wind direction and velocity.

Procedure: Draw the true heading (70°) on the chart, and in length make it equal to the true air speed. Use the mileage scale on your chart. From the starting point of this line, draw the track made good (80°).

The second true heading (160°) must be drawn down to join the end of the first true heading line; *i.e.*, when drawn, they will form a right angle open to the left. From the starting point of this 160° line, draw the track made good on this second heading.

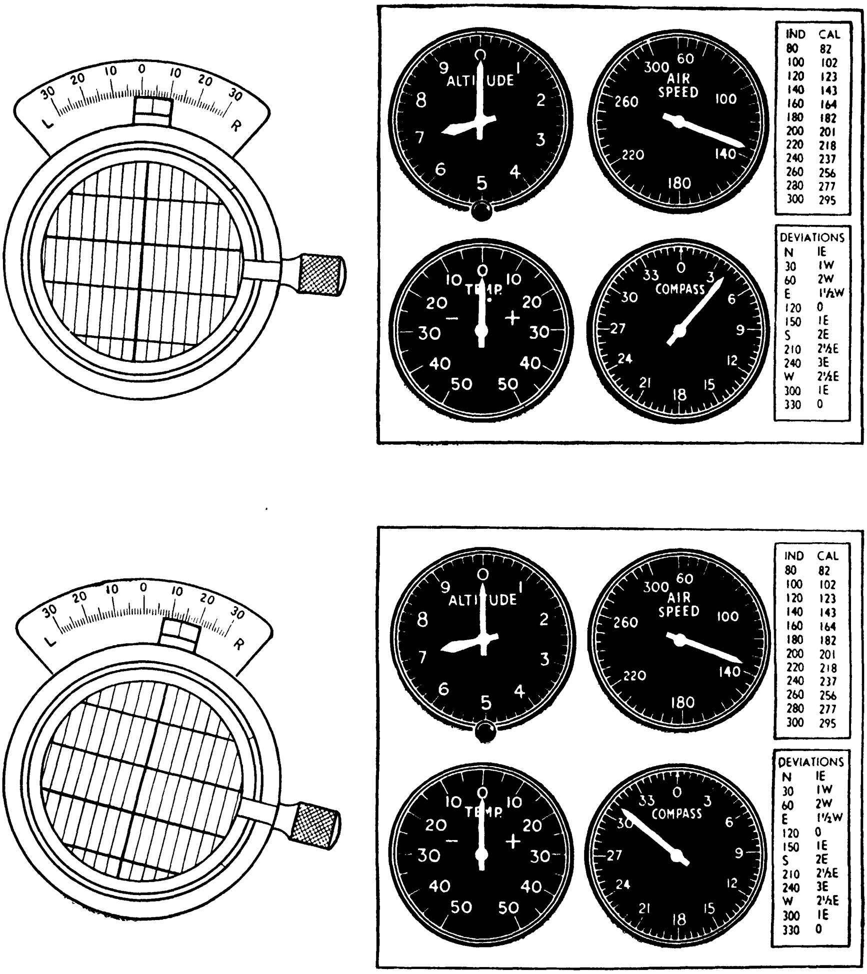


FIG. 135.—Problem 5.

Draw a straight line between the junction of the two headings and the intersection of the two tracks. The tail of the arrow must be placed at the junction of the headings, and the point of the arrow must be placed at the intersection of the tracks. In direction this line represents the direction of the wind; its length is equal to the velocity when measured according to the same scale used in measuring the air speeds.

2. A plane is making 180 m.p.h. true air speed on a true heading of 270°; 15° left drift is observed. The navigator requests a shift of heading to the right, and the plane is steadied down on a true heading of 322°; 5° right drift is observed.

Required: Wind direction and velocity and ground speed on the first heading.

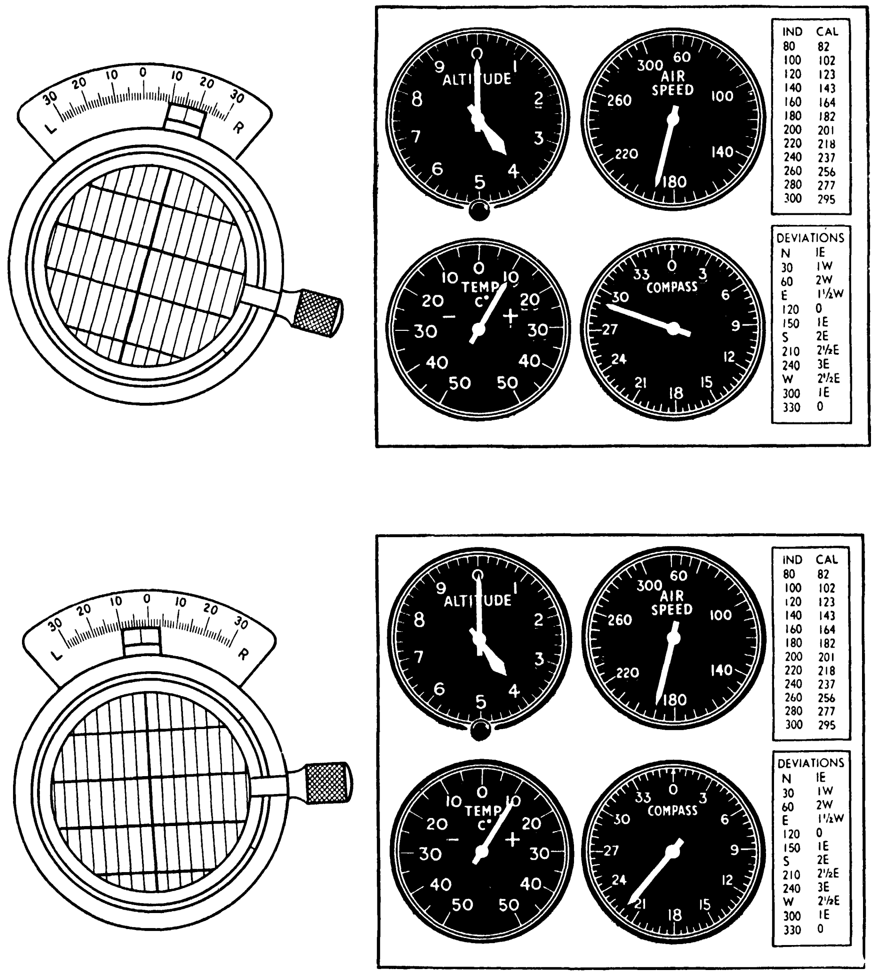


Fig. 136.—Problem 6.

3. A plane is making 130 m.p.h. true air speed on a true heading of 180°; 20° right drift is observed. The plane is put on a true heading of 240°, and 10° right drift is observed. Following this, the heading is changed to 120°, and 10° right drift is observed.

Required: The wind direction and velocity and ground speed on the first heading.

4. From the information shown on the two views (Fig. 134) of the navigator's instrument panel and the two drift readings determine (*a*) the wind direction and velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 350° and the anticipated ground speed. The local variation is 10°W.

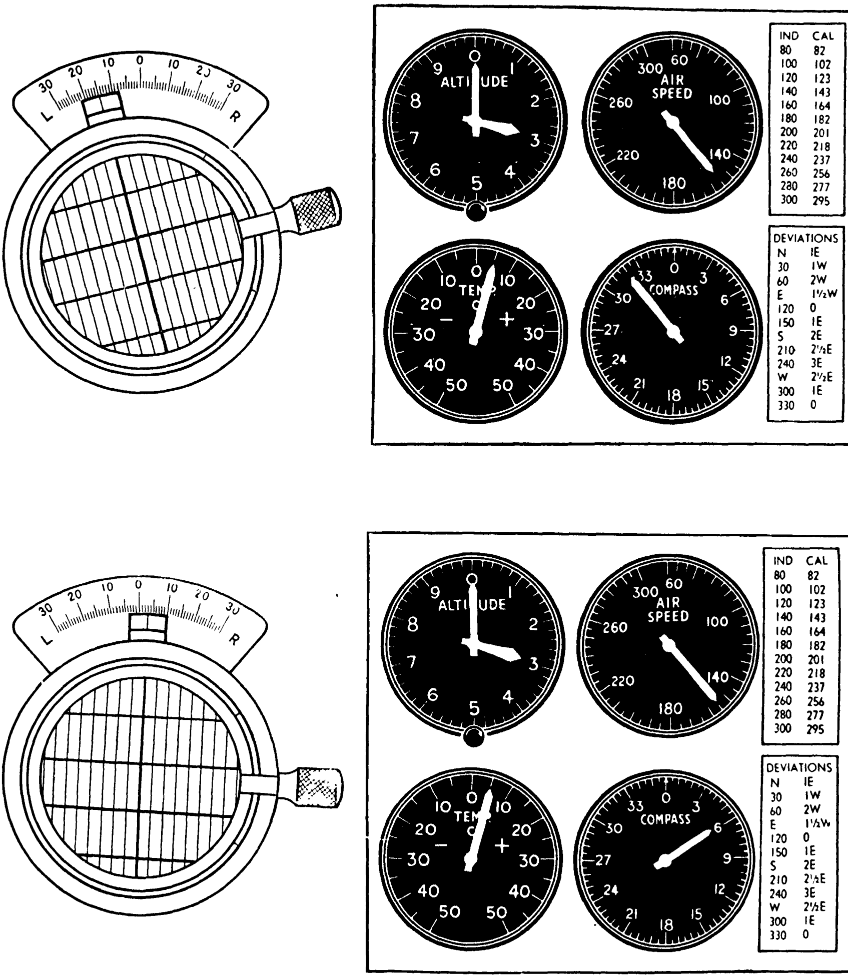


Fig. 137.—Problem 7.

5. From the information shown on the two views of the navigator's instrument panel (Fig. 135) and the two drift readings determine (*a*) the wind direction and velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 20° and the anticipated ground speed. The local variation is 2°E.

6. From the information shown on the two views (Fig. 136) of the navigator's instrument panel and the two drift readings determine (*a*) the wind direction and velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 275° and the anticipated ground speed. The local variation is 3°W.

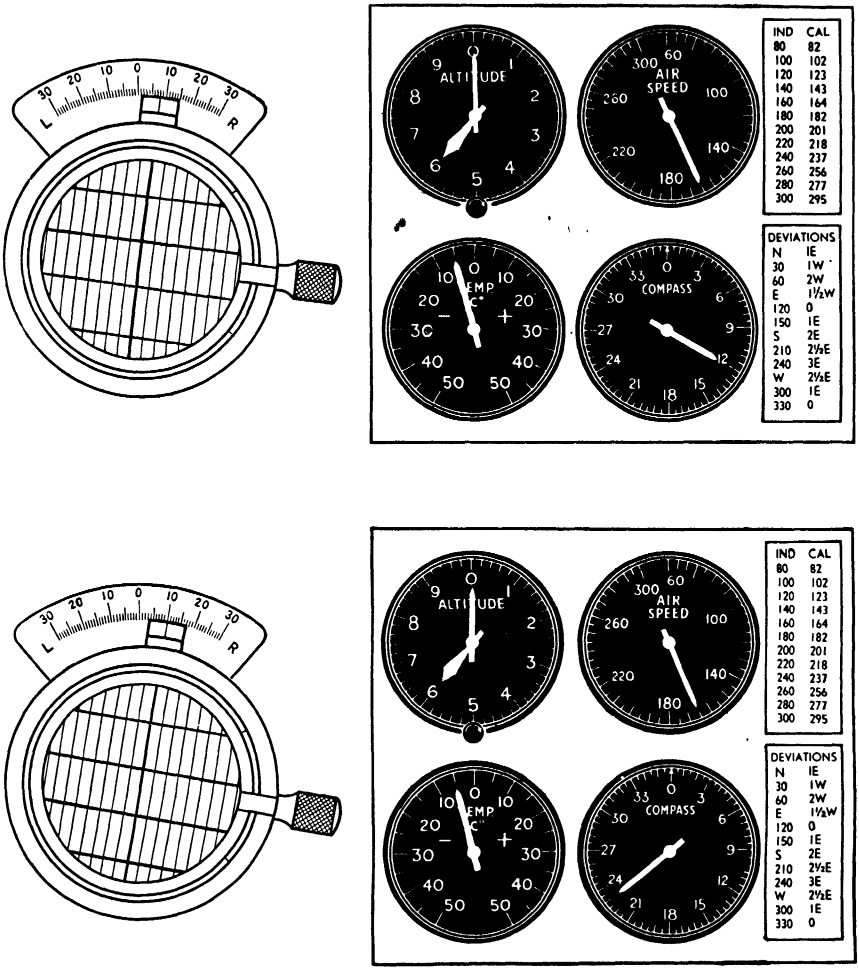


FIG. 138.—Problem 8.

7. From the information shown on the two views (Fig. 137) of the navigator's instrument panel and the two drift readings determine (*a*) the wind direction and velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 320° and the anticipated ground speed. The local variation is 17°W.

8. From the information shown on the two views (Fig. 138) of the navigator's instrument panel and the two drift readings determine (*a*) the wind direction and

velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 85° and the anticipated ground speed. The local variation is 1°E.

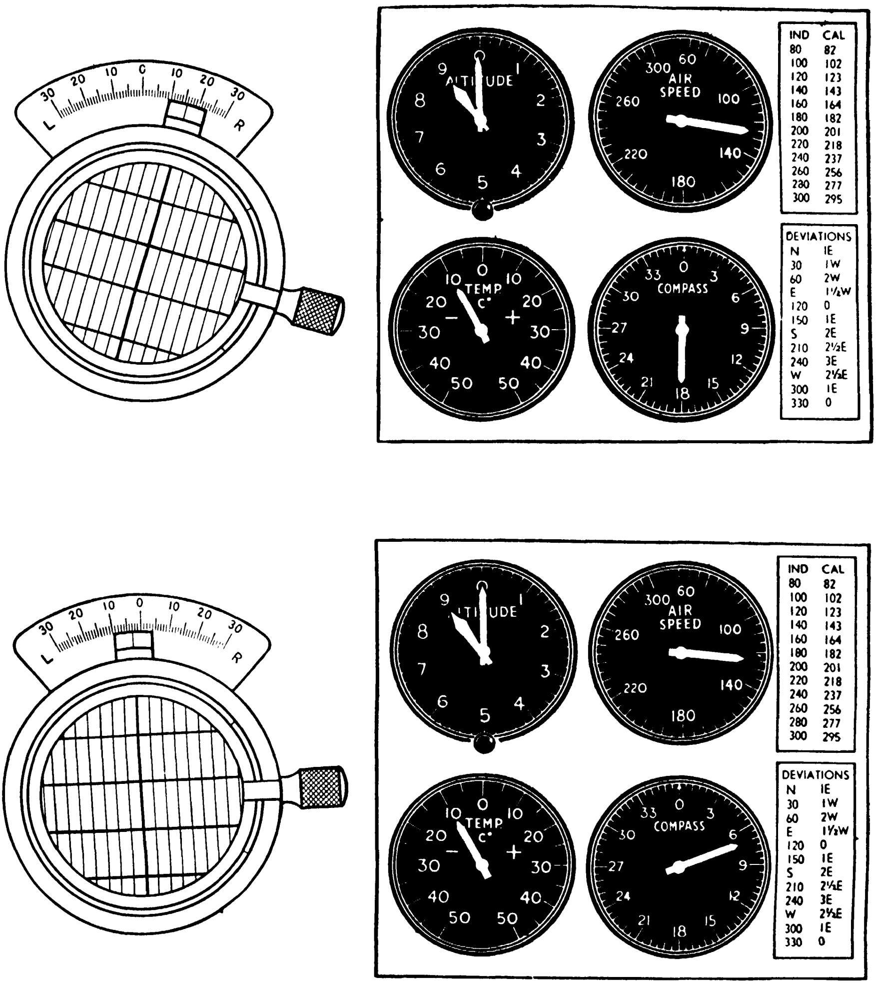


Fig. 139.—Problem 9.

9. From the information shown on the two views (Fig. 139) of the navigator's instrument panel and the two drift readings determine (*a*) the wind direction and velocity, (*b*) the track and ground speed made good on the first heading, and (*c*) the compass heading required to make track 140° and the anticipated ground speed. The local variation is 11°E.

CHAPTER V

RADIO AIDS TO NAVIGATION

One of the principal aids to air navigation is the system of radio-range stations that radiate on-course signals along the airways. The on-course signal consists of a long continuous dash unbroken except for transmission of the identifying Morse code signal of the station. For the most part the stations are located a few miles from important airfields in order that they

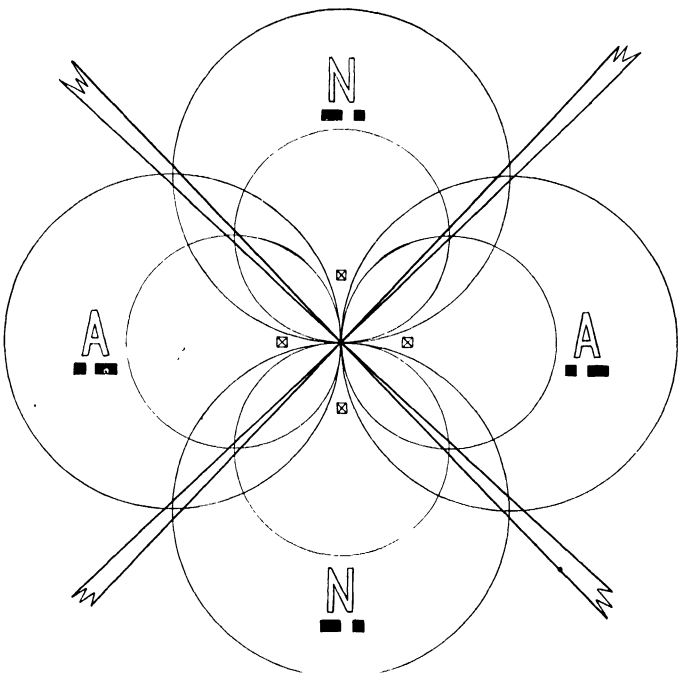


FIG. 140.—A United States radio-range pattern.

may be utilized for orientation purposes at the field in bad weather as well as for guidance along the airway itself. The four-tower vertical antenna system with radio transmitter in the middle may be easily recognized in clear weather. Knowledge of the manner in which the beams are formed may help the student in his study of orientation problems, and the topic will be briefly discussed in the following paragraph.

The north and south antennas shown in Fig. 140 transmit the international Morse code letter "N," consisting of a dash and a dot; the east and west antennas transmit the letter "A," consisting of a dot and a dash. The transmission of these letters is timed so that a pilot situated where both can be heard with equal intensity hears the spaces of the N transmission filled in with the dots and dashes of the A. A long dash results. This long dash, interrupted only by the station's identifying Morse

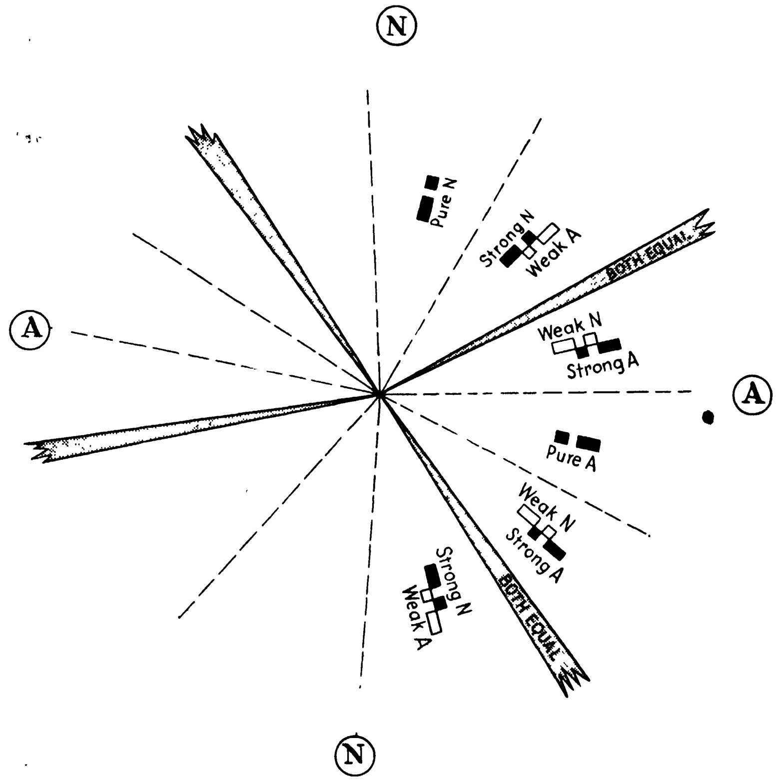


FIG. 141.—Signals emanating from a radio-range station.

signal, constitutes the range leg. This beam covers an arc of about 3°; it radiates from the station and may attain a width of 6 miles or more at a distance of 120 miles from the transmitter. On either side of the beam is an area in which the transmission from both an A and an N tower may still be heard but in which the transmission of one is diminished enough to create but a low monotonous undertone in the spaces of the predominating signal. The areas in which both A and N transmissions are heard comprises about two-thirds of the area between the on-course legs. Midway between the legs a pure A or N is heard. This is shown in Fig. 141.

The radio-range stations are shown in red on sectional and regional aeronautical charts. Information regarding the radio frequency of transmission, Morse identification signal, time of weather broadcasts, etc., is usually printed on the chart near the station. The N and A signals are interrupted every half minute for transmission of the identification signal. The identification is always transmitted first by the N towers and then by the A towers.

Provision is made at most of the range stations to transmit weather information so that the pilot may keep informed while tuned to the beam along which he is flying. All range receivers have a switch labeled "Range," "Voice," and "Both" so as to separate weather from signals when desired. Generally, where weather information is broadcast, five antennas instead of four are used.

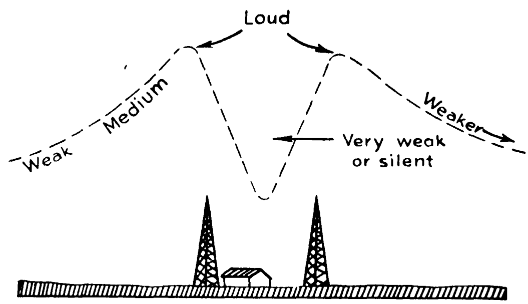


FIG. 142.—Cone of silence above a radio-range station.

Above each of the beam stations is an inverted cone of silence in which little or no signal is heard and by means of which the pilot may locate the station as he flies over it. The strength of the signal builds up as the plane approaches the station, stops as it goes through the cone of silence, builds up again with a noticeable surge as it passes out of the cone of silence, and then gradually diminishes as the plane leaves the station behind. Relative signal strength around the cone is represented by the dotted line in Fig. 142. Generally, the cone of silence is found directly above the station, although occasionally it is found to lean a little from the vertical. At high altitudes a plane will not be directly over the station when it passes through such a cone.

Marker Beacons—Class M.—At numerous points along the track the pilot will find low-powered nondirective radio stations operating on the same frequency as the beam. The range of these transmitters is 10 to 15 miles, and they serve to check the plane's progress along the airway. Where a marker beacon is located at the intersection of two beams that operate on different frequencies, it operates on both. Occasionally, marker beacons are located near obstructions, such as towers or

high terrain. They do not operate continuously but function when the sky is more than one-tenth overcast or on request. Most of them are equipped for two-way voice communication. They may be identified on the aeronautical charts by a red broken circle around the station.

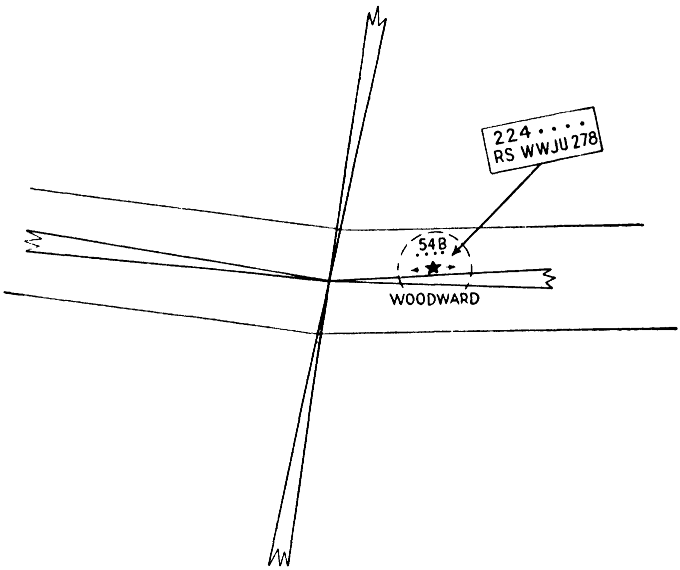


FIG. 143.—Marker beacon—class M.

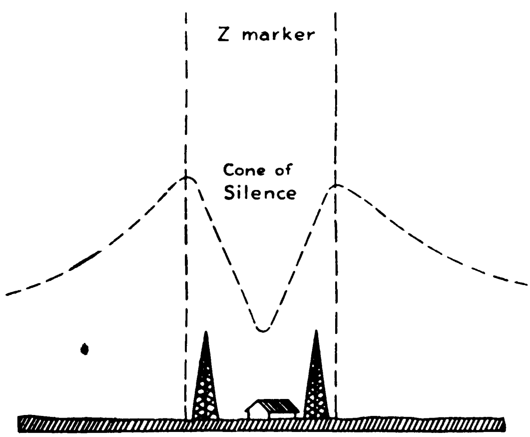


FIG. 144.—Marker beacon—class Z.

Near the circle is a notation as to the call letters and **voice frequency** as well as **marker-beacon frequency** and identifying Morse signal.

Marker Beacons—Class Z.—Class Z markers are located at radio-range stations and transmit a high-pitched note in and near the cone of

silence. This signal is unbroken and may be heard after the radio-range signal fades out in the cone of silence.

Fan Marker Beacons.—Fan marker beacons (so called because the area in which they are heard corresponds roughly to a thick fan across the airway) are located on the beams about 20 miles from many major airports. The characteristic note is high-pitched and is transmitted as a series of single dashes if the fan is located on the northeast leg of the beam, as a series of two dashes if located on the southeast beam, three if on the southwest beam, and four if on the northwest beam.

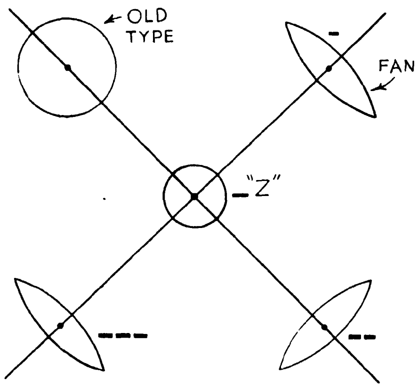


FIG. 145.—Fan marker beacons on radio-range legs.

Unless the aircraft is equipped with a receiver capable of tuning in 75 megacycles, neither the fan marker nor the Z type marker beacons can be heard.

Peculiarities of Radio Ranges.—In mountainous country radio ranges are to be used with caution since the beams may be deflected from their normal paths by terrain. Beams do not pass through mountains; the danger lies in losing them. If the pilot alters headings radically to keep

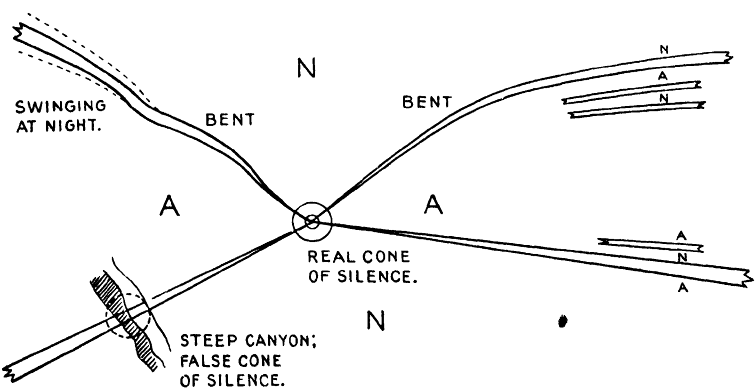


FIG. 146.—Peculiarities of radio-range legs.

on a bent beam and loses it, he may because of high near-by mountains be prevented from searching in an effort to get back on the beam. The only safe procedure at any station is to acquire "local knowledge" under daylight contact conditions.

Another difficulty encountered in using radio ranges in mountainous country is that the beam sometimes splits up into a number of narrow on-course bands, some of which may lead over dangerously high ground. Were it not for the latter consideration even a false on-course signal could be followed into the station. On leaving the station a close check on the plane's heading should be maintained in order to eliminate the possibility of following a split beam into danger.

Orientation at a Radio-range Station.—Under contact conditions a prudent pilot always approaches and leaves an airport according to some prearranged and carefully considered plan of flight. The location of obstructions such as chimneys, radio towers, or mountain ranges is carefully noted, the wind is studied, and only then is the take-off or approach commenced. Since such care is considered necessary under contact flight conditions, the importance of even more careful planning under instrument or near-instrument conditions needs no emphasis. If the take-off is from a field where weather conditions are near minimum, the pilot may lose visual contact with the ground almost immediately and the track must be such that it clears all obstructions by a wide margin. After take-off it is a relatively simple matter to pick up the proper leg of the near-by radio-range station and follow it out along the airway; even so, a definite procedure should be followed, which naturally will vary with each airport.

The problem becomes more difficult when the pilot, not knowing the exact position of the plane, is obliged to orient himself at a radio-range station. The student should think of instrument approaches not as something to be used only under conditions of low visibility at the airport; under overcast conditions the proximity of high mountain ranges may force such an approach even though clear weather exists at the airport itself. This is especially true in the western United States, where several of the largest airports are located in valleys. Correct instrument-approach procedure is so important that all major air lines require their pilots to drill continuously on so-called "standard" approaches to both regular and alternate airports. These standard procedures specifying minimum approach altitudes, tracks, and letdowns are drawn up by experts. Specific procedures followed by individual air lines must be obtained from the instrument flight department of the air line with which the pilot becomes associated. However, since orientation at a radio-range station constitutes a navigational problem, a discussion of this portion of instrument flight procedure will be helpful.

90° Method of Orientation.—Let us assume that a plane is heading north on instruments in the vicinity of New Hackensack, N.Y. The pilot must pass over the range station near the field before commencing his letdown and final approach. His radio receiver is tuned to the frequency

of the range, 236 kc., and he hears a long dash and dot in his earphones, indicating that he is in one of the N sectors. A study of Fig. 147 will show that he could be either in the northwest or in the southeast quadrant.

He believes that he is at *X* but realizes that he may be at *Y*; his problem is to orient himself and pass over the station. He heads his

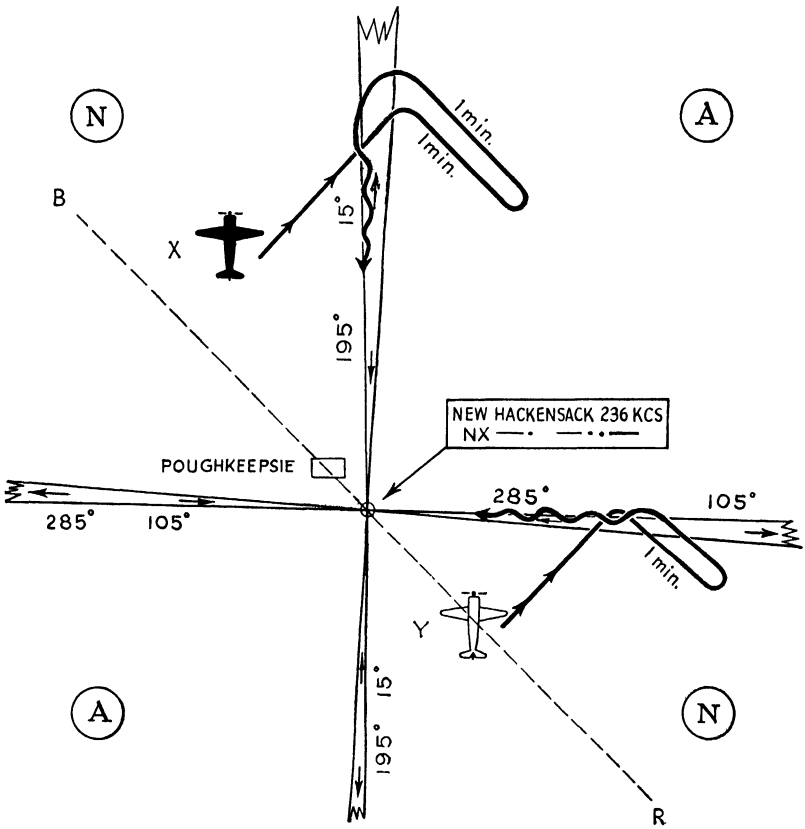


FIG. 147.—Ninety-degree method of orientation at a radio-range station.

plane at right angles to the average bisector *BR*, shown on the diagram. The exact heading may be determined as follows: Two beams border position *X*, and on these beams are printed the magnetic directions into and away from the station. The same is true for the beams bordering position *Y*. Add the magnetic directions *into* the station along the beams bordering position *X* to the magnetic directions *away* from the station along the beams bordering *Y*. Divide by 4. This establishes the direction of line *BR*.

Since the pilot is to fly at right angles to this line, he will either add or subtract 90° from this direction. In this case, flying north, he elected to turn right and accordingly headed his plane 150 less 90, or 60°. On this heading he will eventually intersect either the north or the east leg of the station. On passing through the beam, still unidentified, the pilot turned 90° right. If the pilot began the orientation problem in the southeast quadrant, the last right turn should bring the plane back into the same quadrant and the N signal should be heard again. However, had the plane been in the northwest N quadrant, the last right turn would have brought it into the northeast quadrant, where an A signal would have been heard. Identification of the quadrant in either case brings about identification of the leg intercepted. If the pilot was near position X when he commenced his orientation problem, he could not have intercepted any New Hackensack beam other than that radiating north from the station. Regardless, however, of the quadrant into which the final right turn brought him, he may now make a left turn (180°), pick up either leg, and bracket it to the left into the station. Had he elected to turn to a magnetic heading of 240° instead of 60°, he would have intercepted the south or west leg; after passing through, a 90° right turn would have enabled him to identify the quadrant, and a left turn (180°) away from the station would have enabled him to pick up the beam and bracket it toward the station.

PROBLEMS

1. The radio-range system at Bellefonte, Pa., is shown in Fig. 148. The pilot hears the letter "N" in his receiver and assumes that he is at X but recognizes that he may be at Y.

Required: (*a*) The average bisector of the N quadrants. (*b*) The initial magnetic heading if the pilot desires to intercept either the north or the east leg.

Ans.: (*a*) 152½. (*b*) 62½.

Inasmuch as headings to the half or full degree are not easily followed, the pilot would probably head either 60° or 65°.

2. Assume the pilot heard the letter "A" in his earphones and elected to intercept either the north or the west leg. What magnetic heading would first be steered? *Ans.:* 332½°.

3. A pilot in the vicinity of the Allentown, Pa., range, identification signal XA, finds himself in one of the N quadrants (see Fig. 149). The pilot hopes he is approaching the station from position X but recognizes that he may be in the northern quadrant going away from the station. He elects to intercept either the northwest or the southwest leg. What magnetic heading should be steered? *Ans.:* 268°.

NOTE: In solving for the average bisector a line through the Allentown range of 178° was obtained, and the fact that the plane was heading approximately north had no bearing on the problem—it never does. The plane could have been heading

south. The magnetic heading of 268° (at right angles to 178°) became necessary because the pilot elected to intercept one of the western legs.

4. Draw in the flight paths from positions X and Y for the preceding problem. Include the turnaway from the station onto the beam after beam identification.

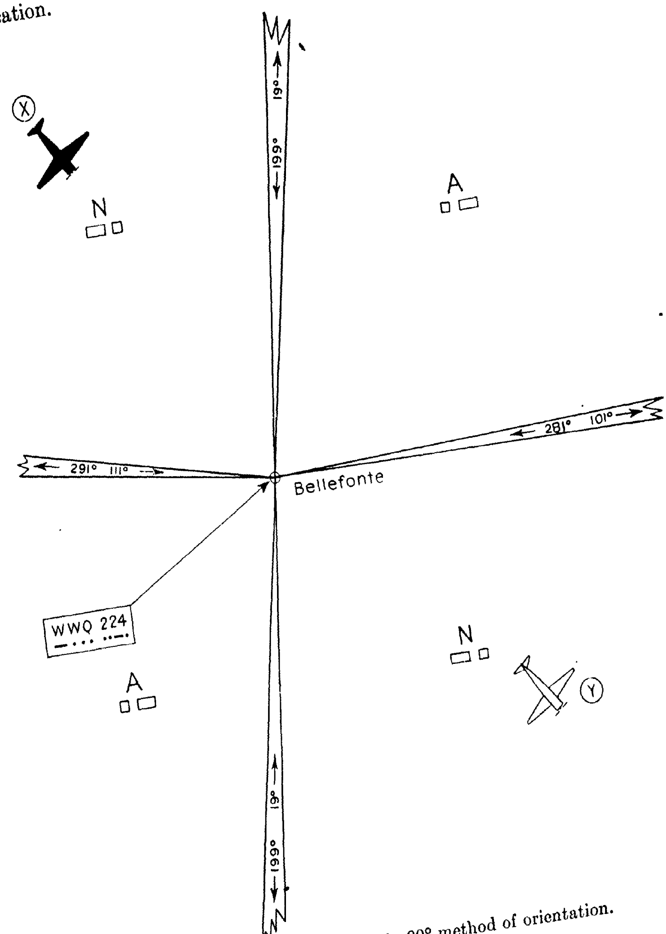


FIG. 148.—Problem in 90° method of orientation.

It should always be remembered that, when a pilot has flown through the beam on a track at right angles to the average bisector and has turned right to identify the quadrant, the turnaway from the station will always be to the left.

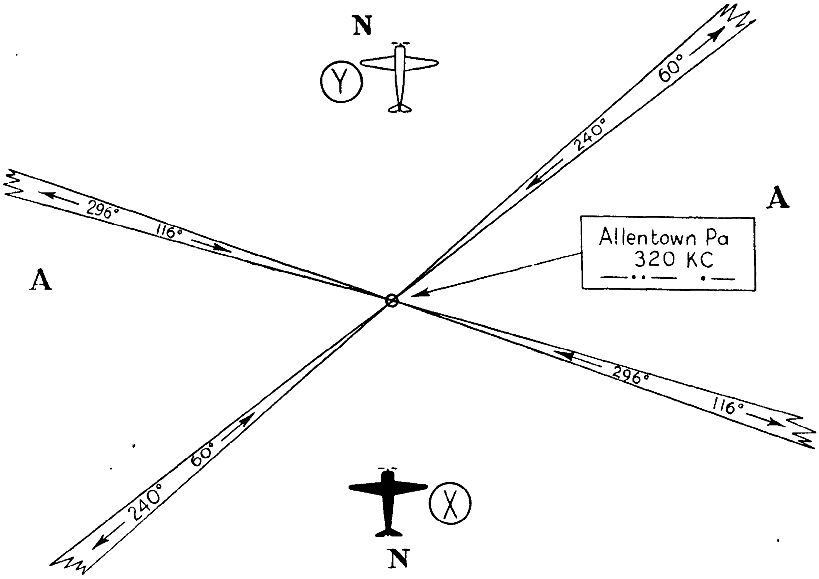


FIG. 149.—Problem 3.

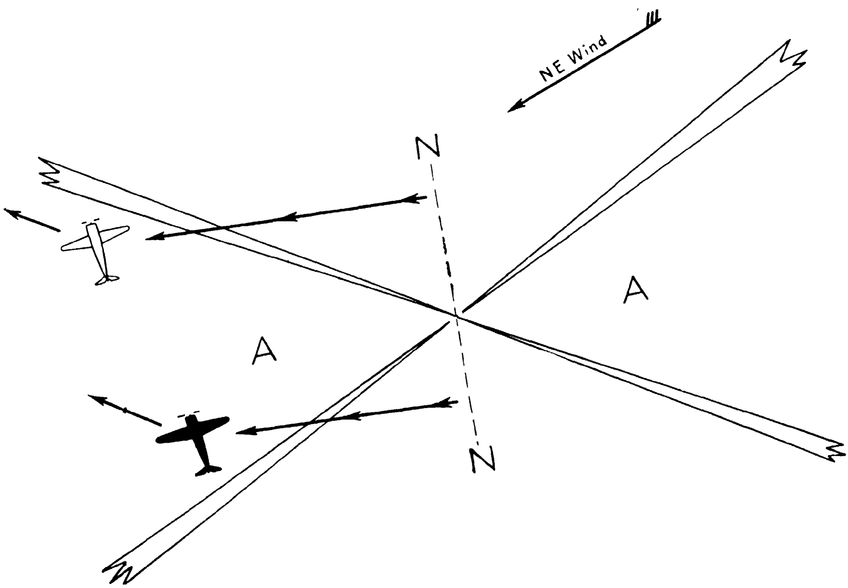


FIG. 150.—Effect of high wind during 90° orientation.

Drawing in the flight paths should have shown the student that in this case a quick orientation might not be achieved. The heading of the plane was such that it tended to parallel the beams the pilot wished to intercept. Had a strong southerly wind existed without the pilot's knowledge, the heading might have resulted in a track that literally would have paralleled the northwest leg and it would never have been intercepted. In point of fact, in Prob. 4 a totally false answer to the orientation problem would result under high northeasterly wind conditions. Had the pilot made a right turn after intercepting the northwest leg, his track would have more or less paralleled the northwest leg.

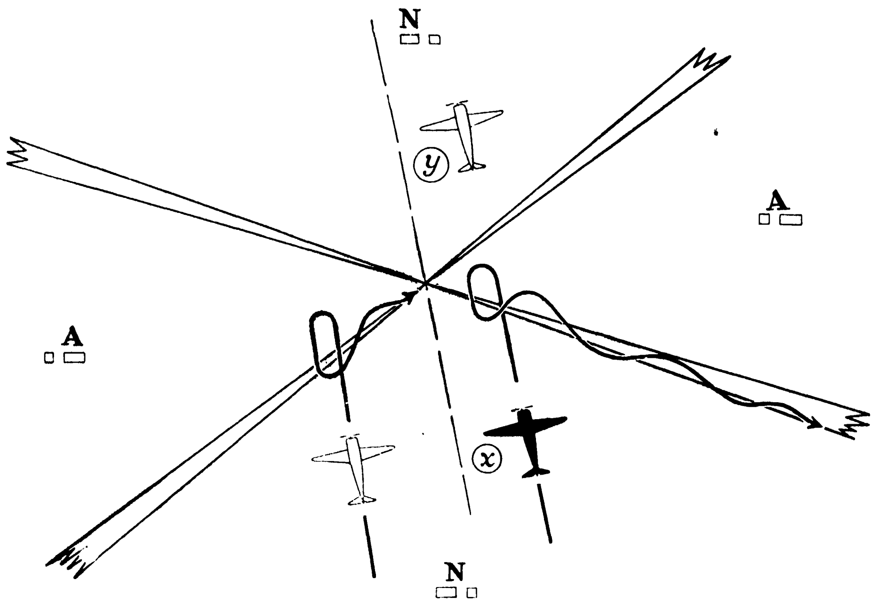


FIG. 151.—True fade method of orientation.

Absence of a change of signal from A to N would, after a brief time, have convinced him that he had intercepted the southwest leg. A study of Fig. 150 will show the actual flight paths and illustrate how false orientation occurs.

Thus we find that the 90° method of orientation has very definite limitations. It is not well suited to beam patterns with wide (greater than 90°) quadrants. For such orientation problems, the fade-out, or parallel fade, method is more suitable.

True Fade-out Method of Orientation.—Using the same Allentown range under the same conditions (see Prob. 3, page 137) a quicker and surer approach could be made with the true fade-out method. The pilot determines the average bisector of the two N quadrants in the manner previously described. Then, instead of heading at right angles to this

average bisector, he flies parallel to it, and with the receiver volume at a moderately low level he listens intently for a fade or build-up of signal strength. If he is approaching the station from position X, as he hopes he is, the signal strength will increase. If it decreases, however, he is on the other side going away from the station.

Let us assume that the signal strength increases. If the plane was heading north, it must be in the southern N quadrant. But identification of the quadrant has not in this case identified the leg the plane will intercept if it continues in straight flight. There is no way of ascertaining whether the plane is heading straight for the station or toward the southeast or southwest leg. The pilot continues on his way, however, hoping he will not pass so close to the station that the beams are crossed too quickly to permit orientation. Let us assume that this does not happen and that he intercepts either the southeast or the southwest leg. After having passed through the beam, he makes a left turn not exceeding 180° and picks up the on-course signal. He brackets the right side of the range leg with his receiver turned low and again listens for a fade or build-up. If the signal fades, he is moving out along the southeast leg; if it builds up, he is coming in on the southwest leg. If the latter situation is satisfactory, he continues in, gets an enormous build-up at the edge of the cone of silence, then complete silence, then a rush of signal strength and a gradual fade as the plane proceeds away from the station. If, however, the signal strength decreases and he finds himself moving out along the southeast leg, he may make a turn to the left, cross the beam, pick up the right-hand side, and bracket it toward the station. He should make every effort to steady the plane down as it approaches the station, for the beam gets narrower and narrower and may possibly be lost.

Had the plane been at Y or thereabouts, the pilot would have made a turn of 180° and headed toward the station paralleling the average bisector. From then on he would have followed the procedure explained above, but of course he would have intercepted a different leg.

Parallel Fade Method of Orientation.—The disadvantage of the true fade-out method lies in the fact that the pilot does not know beforehand which leg of the beam he will intercept. This difficulty (after quadrant identification) may be eliminated by maintaining a heading that will make the plane parallel one of the legs. In this case (with the plane in the southern quadrant), had the pilot desired to make his first approach on the southwest leg, he would have maintained a magnetic heading of approximately 296°, a heading that sooner or later would have carried the plane through the southwest leg. On passing through he should turn 45° away from the station for 1 min., then 180° back to pick up the beam again, and bracket the right side into the cone of silence.

Use of True or Magnetic Directions.—In all the orientation problems we have determined the bisectors of the radio-range quadrants by using magnetic-beam directions instead of *true directions.* We have flown parallel to the magnetic bisectors and at right angles to them and have called these magnetic directions *tracks.* We have assumed that these magnetic tracks could be followed by using a plane's compass, knowing that most compasses do not point out exact magnetic directions. Finally, we have assumed that no wind existed. We have come to a point where it may well be asked just what is theoretical and what practical regarding true and magnetic directions.

In the study of the triangle of velocities (page 4), all sides were expressed as true directions. Practical considerations, one of which is the universal practice of forecasting wind in true directions, make this advisable. It would be possible but impractical to forecast wind in magnetic directions since a wind of 250° magnetic at Boston is quite different from a wind of 250° magnetic at St. Louis. In planning and executing a long cross-country flight it is convenient for this reason to deal with true directions only.

On the other hand, while using magnetic compasses it would be impractical to make an instrument approach based on true directions. Compass readings are usually nearer magnetic than true. A quick glance at the magnetic-beam directions printed on the chart suffices to establish approximate compass headings. Allowance for wind effect is made by trial and error, and little time is available to work out nice navigational problems using true directions. Indeed, owing to the time lag involved, it is doubtful if precision would be gained if the problem were approached from this angle.

QDM Approach.—In international radio terminology the term **QDM** means, "Steer ——° magnetic to reach me with no wind." Instrument approaches by means of QDM's were standard procedure in many European countries a few years ago. Planes approaching fields on instruments requested QDM's; magnetic bearings of the plane were taken, and the reciprocals were transmitted by radio for the use of the pilot. On receipt of the message "QDM 10°," for example, the plane was headed 10° magnetic (plus or minus allowance for wind), and the station was approached directly.

A modification of this type of instrument approach is used in this country in the operation of large flying boats, since they land in water areas where conventional beam installations are seldom found. Instead of requesting QDM's from the shore station they request the station to transmit continuously and approach by means of magnetic bearings that they themselves obtain. The method of orientation and approach by QDM's has many advantages over orientation and approach by means of

radio beams. Identification of a beam and quadrant is unnecessary, since from the very start of the approach the plane flies along a definite track toward the station. Somewhat less precision in steering is needed since it is unnecessary to keep on a narrow beam; in rough air this is a considerable advantage. It is unnecessary to pass directly over the station through a small cone of silence; indeed, a more gradual indication of approach and passage is often obtained by deliberately passing a little to one side of the transmitter.

When automatic direction-finding (A.D.F.) equipment is used, the A.D.F. needle points toward the station; as the plane goes by, it will swing around and point astern. At low altitudes when, by chance or intention, the plane passes directly over the transmitter, the needle reverses itself very quickly with little warning. At an altitude of 8,000 ft., however, the author has seen the needle hunt from side to side for a period of 2 min. before the plane reached the station. This hunting characteristic varies with different types of radio equipment, but with one well-known and reliable automatic direction finder the needle hunted 20° either side of the bow. This could prove disconcerting to one unfamiliar with A.D.F. equipment; to the experienced pilot, however, it is one of the indications that the plane is very close to the transmitter. As stated before, the approach is frequently made to one side of the transmitter in order to give a positive and gradual indication of passing the station. Allowance for the effect of the wind is made by heading the plane sufficiently left or right of the needle indication to prevent a shift of bearing.

From a navigator's standpoint the QDM approach has distinct advantages over other methods. The plane is never "lost." After the first "over," a definite prearranged pattern of flight is followed, and after the second over the final letdown to the landing area is made. Needless to say, the QDM approach at any given station is standardized. Minimum safe approach altitude, the proper no-wind headings, and the correct rates of descent are prescribed in great detail. If the landing area is not sighted within a specified interval after the last over, the plane is pulled up and a second approach begun.

A typical QDM orientation pattern is shown in Fig. 152. The first approach is made on a QDM of 330° at 1,800 ft. and 115 knots calibrated air speed, and the plane continues on the same heading for 3 min. after the first over. The student will observe that the station's magnetic bearing of 330° changes to 150° as soon as the plane passes over. At the end of the 3-min. run a turn is made to the right (to 90° magnetic), and the descent is begun. Just before the automatic direction finder shows a QDM of 205° magnetic, the heading is shifted right and steadied down on the 205° bearing. The descent is continued to a minimum

altitude of 1,000 ft. The 205° QDM reverses and becomes a QDM of 25° as the plane passes over the station the second time, but the 205° magnetic heading is maintained to the landing area. The descent is continued to a minimum safe altitude. Failure to make visual contact with the landing area at this altitude leaves no safe alternative but to pull up and try again.

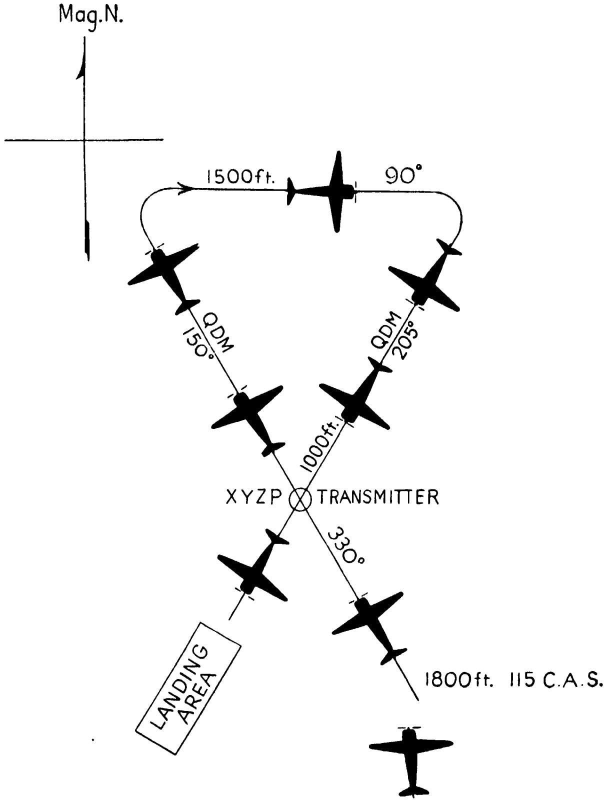


FIG. 152.—A QDM approach.

The pilot assumes in making an approach on QDM's that the compass has very little deviation and that he may steer the magnetic headings obtained through the use of QDM's with little resulting error. From the pilot's standpoint his first problem is to approach the station at a safe altitude and establish an over; his second problem is to follow a flight pattern such that when the second over is made the plane will be in position for a safe and easy descent to the landing area. From the navigator's standpoint the problem consists in supplying QDM's (magnetic bearings on the station) to the pilot for his use in following the desired flight pattern.

The Duties of the Navigator during an Approach Made with an Automatic Direction Finder.—An instrument similar to that shown in Fig. 153 is mounted near or on the instrument panel. The dummy compass (on which the degree markings are shown) may be rotated by turning the small knob at the lower right-hand side of the instrument. It is the navigator's duty to rotate the degree scale so that the plane's magnetic heading is reindicated on this dummy compass. As long as the navigator continues to do this, the needle points out magnetic bearings of the station. The pilot may or may not wish to fly toward or exactly away from the station—that is *his* problem. The problem of the navigator is to keep this dummy compass lined up in direction with the actual steering

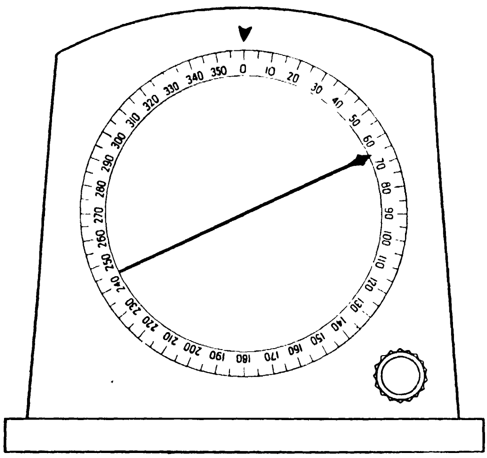


Fig. 153.—Automatic radio direction finder.

compass. In point of fact, the pilots themselves frequently make this adjustment, and the navigator stands by with a chart of the area.

The Navigator's Duty When Manual Direction-finding Equipment Is Used.—When the QDM approach is made by means of a manual direction finder, the actual manipulation of the loop antenna is usually done by the radio officer. Bearings obtained in this manner are measured clockwise throughout 360° from the aircraft's head. The station, for example, will bear 0° relative to the head when the plane is pointed toward the station; it will bear 90° when it is at right angles to the right-hand side of the plane; and it will bear 220° relative to the head when it is 40° from astern but on the left-hand side of the plane. These bearings are purely relative bearings, *i.e.*, relative to the aircraft's head, and have no specific direction as such until referred to the magnetic heading of the plane. If the plane were headed 20° magnetic, for example, when the above bearings were obtained, the magnetic bearings

of the station would have been first 20° (straight ahead), next 110°, and finally 240°. This statement could be amplified indefinitely but it serves to show that the magnetic bearings of the station are obtained by adding the magnetic heading of the plane to the relative bearing furnished by the radio officer. The navigator's duty throughout the QDM approach is to add these two values and repeat the sum to the pilot.

In order to simplify the arithmetical work, the navigator is supplied in practice with an instrument similar to that shown in Fig. 154. The

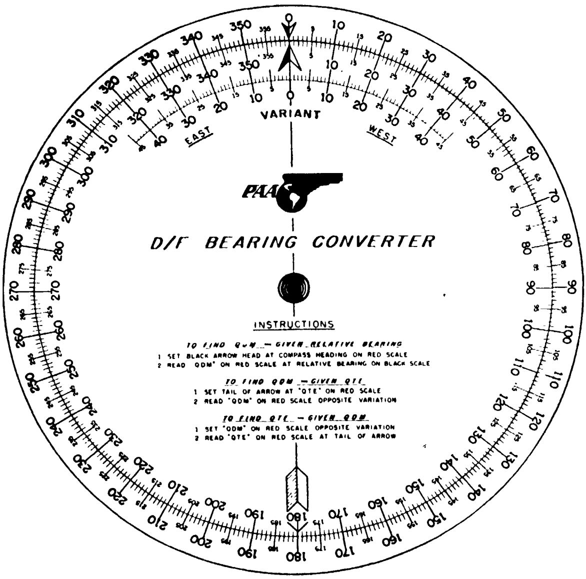


FIG. 154.—D/F bearing converter.

inner disk is rotated until the arrow points to the magnetic direction of flight maintained by the pilot. The relative bearing furnished by the radio officer (directly or through the interphone system) is located on this inner disk, and the number on the outer disk opposite the bearing is repeated to the pilot. Approximately three bearings a minute are supplied when the plane is in straight flight. No bearings are given during a turn because the plane turns too rapidly and the bearings shift too quickly to permit accuracy. The appropriate signal "over" or "passing" is promptly repeated to the pilot immediately on receipt from the radio officer.

CHAPTER VI

LINES OF POSITION AND THEIR USE

It will often be possible for the navigator to say with assurance that his aircraft is somewhere on a line between two cities or points, even though he may not know his exact location within wide limits. Such a line, containing all possible positions of the aircraft, is called a **line of position.** According to this definition highways, railroad tracks, rivers, lake shores, or radio-range legs could be called lines of position. The fact that a single line of position is insufficient in itself to establish a plane's location does not diminish its value. A single line of position may so limit the possible whereabouts of the plane as to contribute materially to the ultimate establishment of a **fix.** The correct usage of lines of position is fundamental in every method of navigation, whether it be radio, celestial, or dead reckoning, and speed and accuracy in handling these lines *must be developed.*

Obtaining and Plotting Radio Lines of Position.—Nearly all domestic air-line planes are equipped with radio direction-finding (D.F.) apparatus. By means of this equipment, radio bearings (lines of position) can be obtained on either radio-range stations or broadcast stations, and the ease with which these bearings may be obtained makes fast and accurate navigation possible. The loop-antenna receiver is tuned to the radio-range or broadcast-station frequency, and an indicating needle immediately points out the bearing of the station. This bearing is purely relative; *i.e.*, if the needle indicates that the radio station bears 40° to the right of the nose of the aircraft, the heading and bearing must be added together to obtain a compass, magnetic, or true bearing. For example, if a *compass heading* of 10° is maintained while the needle points 45° right, the *compass bearing* of the radio station must be 55°. If a *magnetic heading* of 10° is maintained while the needle points 45° right, the *magnetic bearing* of the radio station is 55°. Finally, if a *true heading* of 10° is maintained while the needle points 45° right, the *true bearing* of the radio station is 55°. In other words, the pilot may obtain a compass, magnetic, or true bearing of a radio station by adding the relative direction-finder bearing to the compass, magnetic, or true heading of his plane. Several examples of this principle are shown in Fig. 155.

Modern radio D.F. equipment, such as the Sperry automatic radio direction finder shown in Fig. 156, makes it unnecessary to combine headings and bearings arithmetically.

To obtain the magnetic bearing of a station, the movable inner scale is rotated until the magnetic heading of the airplane is opposite 0 on the variation scale. The pointer indicates a bearing relative to the nose on

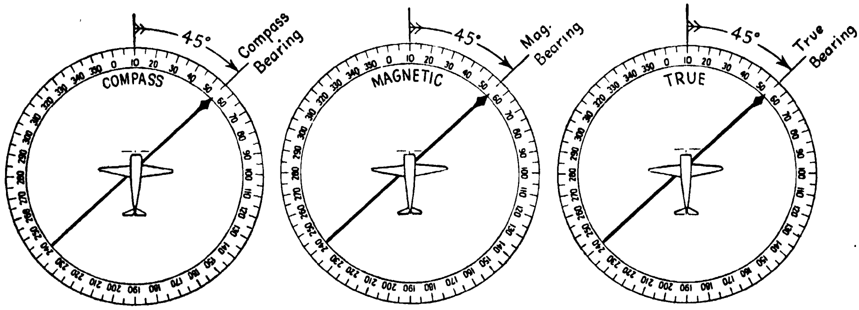


FIG. 155.—Use of relative bearings to obtain compass, magnetic, or true bearings.

the outer fixed scale and the *magnetic bearing* on the inner scale. In Fig. 156 a magnetic heading of 348° is shown set opposite zero variation, and a magnetic bearing of 40° is shown on the inner scale. Note that

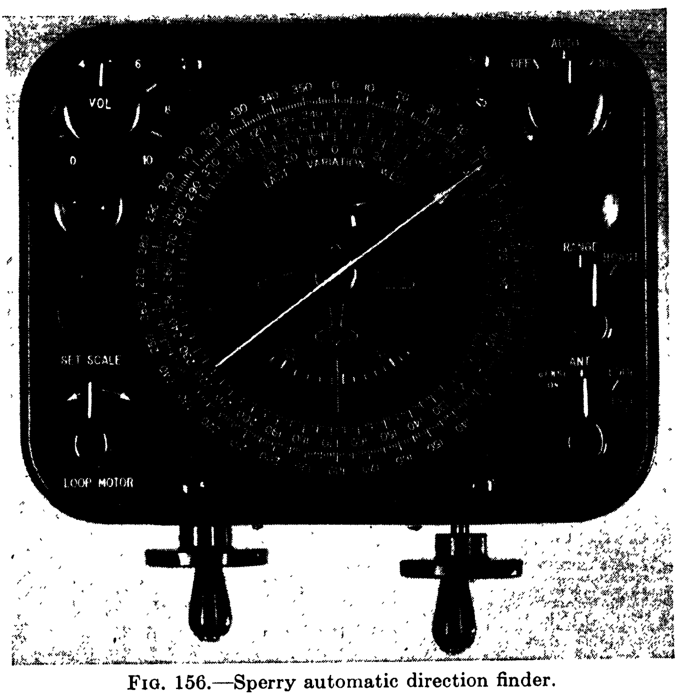


FIG. 156.—Sperry automatic direction finder.

the relative bearing is 52°. True bearings may be obtained by rotating the inner movable scale until the magnetic heading is placed opposite the local magnetic variation. Setting the magnetic heading opposite the

local magnetic variation is equivalent to setting the true heading opposite 0. When this is done, relative bearings will still be indicated on the outer fixed scale and true bearings will be indicated on the inner scale.

In plotting these bearings—and it is suggested that true bearings be used—the navigator is to remember that the true bearing of a radio station is the angle *at the plane's position* between true north and the radio station. Inasmuch as the plane's position is likely to be somewhat in doubt when the bearing is taken, the navigator is forced to estimate his position and measure the true bearing from the meridian nearest his *assumed* position. This may on occasion result in the plotting of a slightly erroneous line of bearing, but if the plane is within 60 miles of the meridian used the error so introduced is less than a mile.

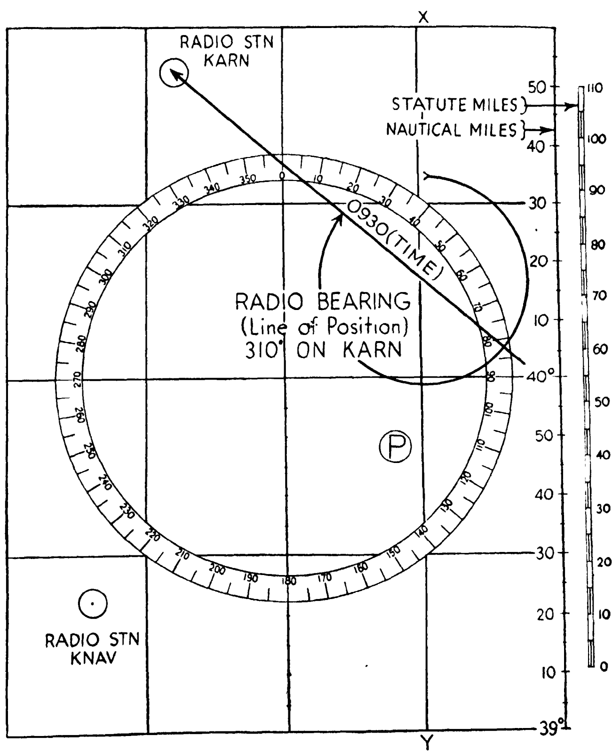


FIG. 157.—Plotting radio bearings on a Lambert chart.

PROBLEMS

1. At 0930 the pilot of a plane near position *P* (Fig. 157) used the automatic direction finder and obtained a true bearing of 310° on radio station KARN.

Required: Plot the radio bearing line of position.

Procedure: Place the center of the protractor on meridian *XY* near position *P*, and rotate it so that 310° lies on the meridian above the center point. Place

a straightedge (a ruler will do) along the base of the protractor. The edge of the ruler will ordinarily come close to the radio station; if it does not, move the protractor up or down the meridian until the ruler passes through the station. Draw the radio line of position from the meridian through the station.

2. A pilot of a plane near position P (Fig. 158) at 1205, using the automatic direction finder, obtains a true bearing of 220° on radio station KNAV.

Required: Draw the radio line of position.

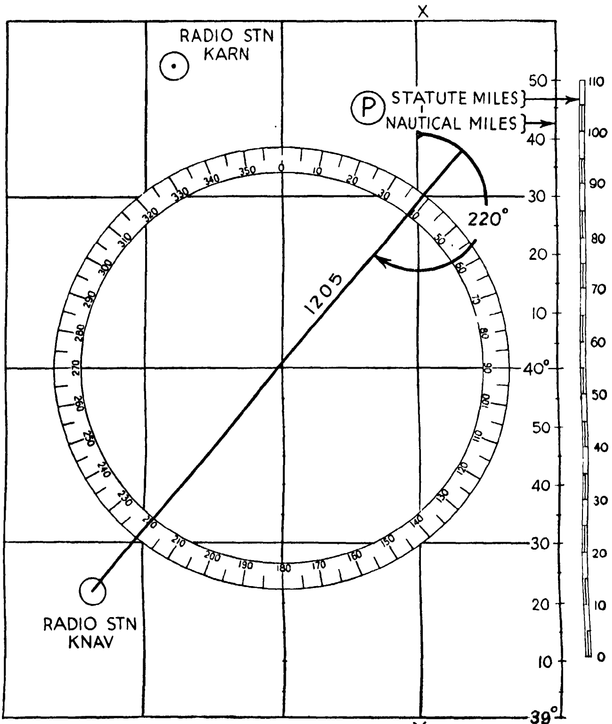


FIG. 158.—Plotting radio bearings on a Lambert chart.

Procedure: The method is the same as in Prob. 1; place the protractor on meridian XY near P so that it indicates an angle of 220°. Place a straightedge along the base of the protractor; and, by moving the protractor and ruler up or down the meridian, make the straightedge pass through radio station KNAV. Draw a straight line from the meridian through the station. If the bearing was taken accurately, the pilot must consider himself to be somewhere along this line.

3. A pilot, assuming himself to be near position P, tunes in on radio station KNAV at 0645 and obtains a true bearing of 200°.

Required: Draw the radio line of position (Fig. 159).

Remark: After plotting this radio line of position, it becomes apparent that the plane was somewhat north of position P.

4. The pilot of a plane near position P at 1315 obtains a true bearing of 340° on radio station KARN (see Fig. 160).

Required: Plot the radio line of position.

Remark: 1315 is 1:15 P.M.

5. The pilot of another plane at the same time, near the same assumed position P, obtains a true bearing of 190° on radio station KNAV (see Fig. 160).

Required: Plot the radio line of position.

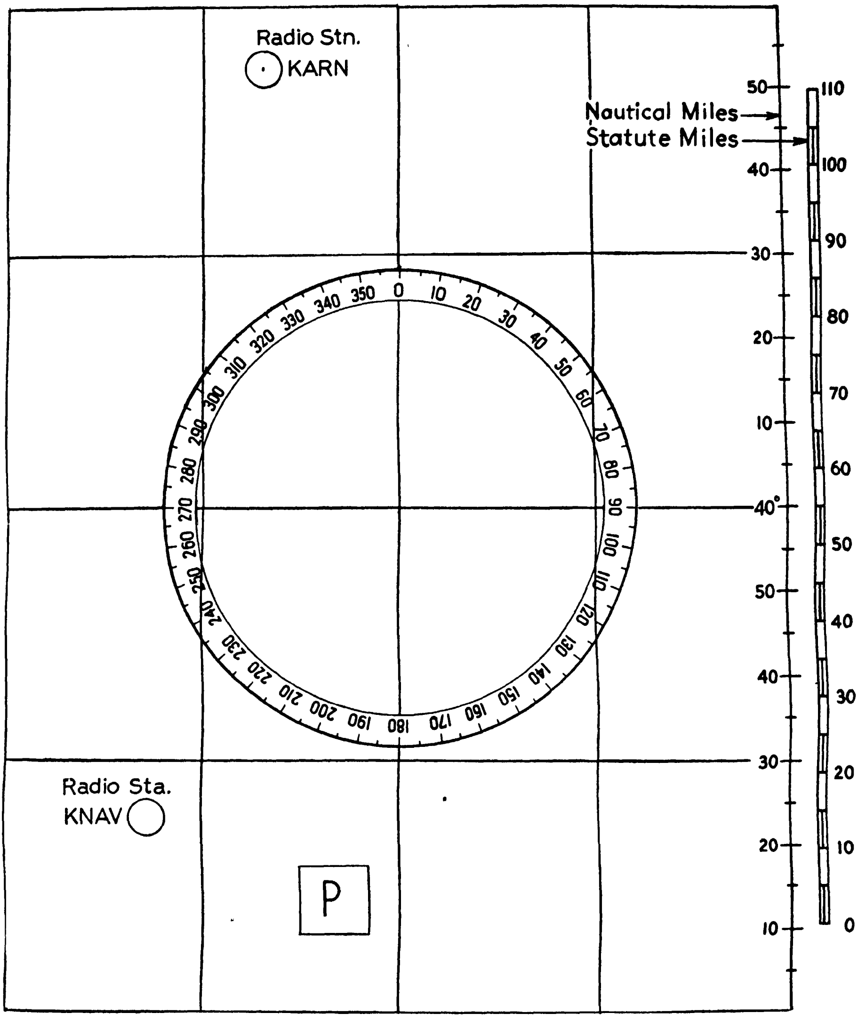


FIG. 159.—Problem 3.

Remark: There is every indication that the plane was west of position P when the bearing was taken.

6. A radio bearing is being taken on radio station KARE; the instruments are shown in Fig. 161. The pilot believes himself to be about 50 miles from the station.

Required: Plot the radio line of position.

NOTE: There should be no question as to the meridian to be used in plotting the bearing, since inspection of the bearing together with the estimated distance from the station should serve to indicate the meridian to be used.

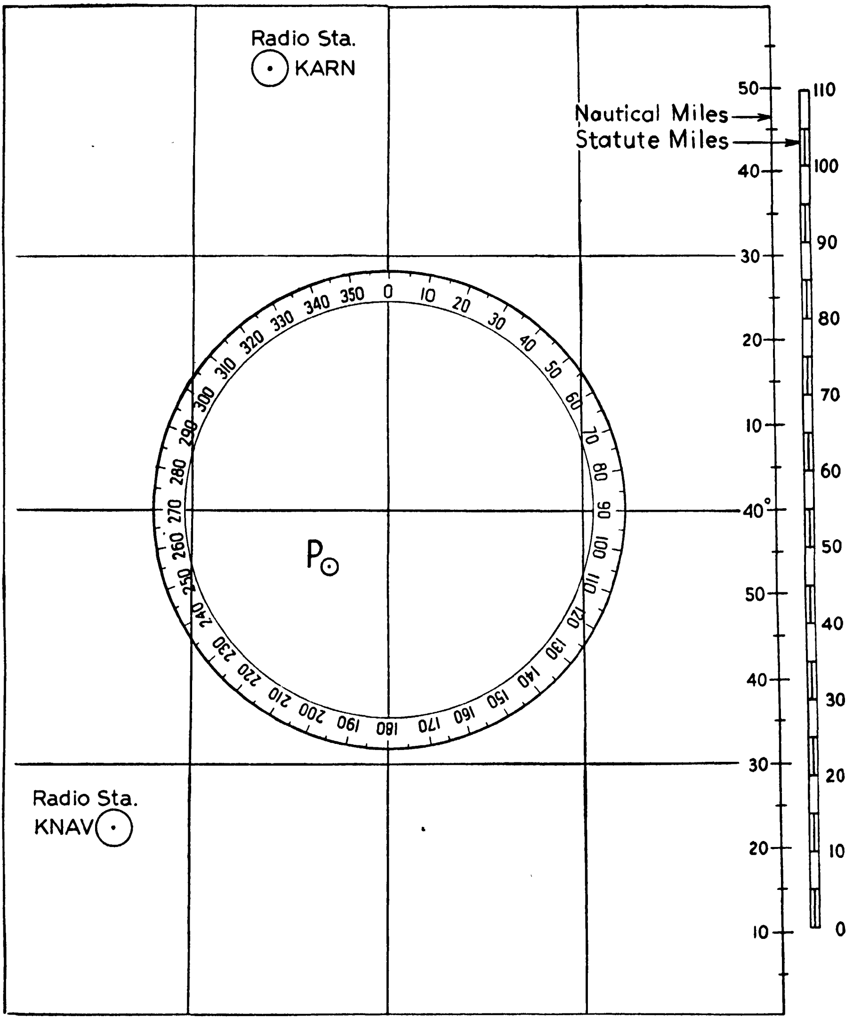


FIG. 160.—Problems 4 and 5.

7. A bearing is being taken on radio station KARE; the instrument panel is shown in Fig. 162. The pilot believes himself to be about 70 miles from the station.

Required: Plot the radio line of position.

8. The pilot of a plane crossing the north shore of Lake Ontario obtains a true bearing of 200° on radio-range station *A* (Fig. 163).

Required: Plot the radio line of position.

Remarks: The plane must be located somewhere on this radio line of position; it is also located somewhere on the north shore of Lake Ontario. There is only one place where a radio bearing of 200° on radio-range station *A* can cross

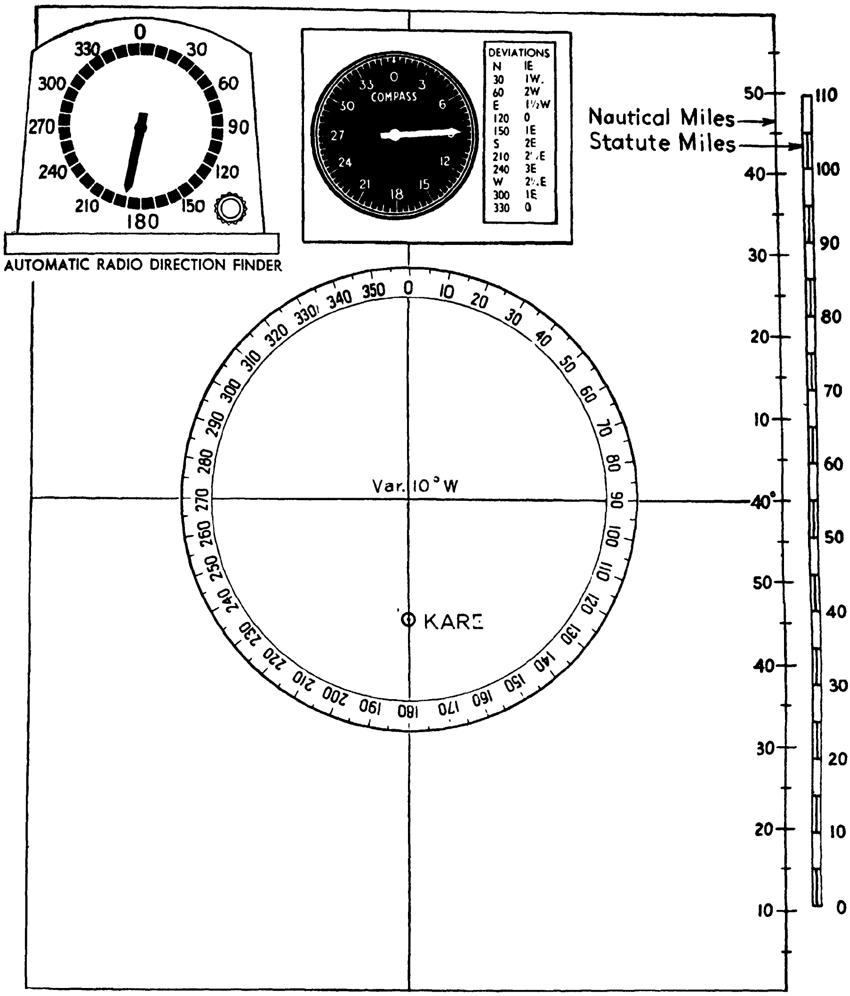


FIG. 161.—Problem 6.

the north shore of Lake Ontario. The position of the plane may therefore be considered fixed at that place.

This problem has been given to illustrate the value of two lines of position in establishing a fix. If the student will recall the definition of a line of position, it will become evident that the intersection of two such

lines will establish a fix. If a pilot finds himself at the intersection of two radio-range legs, for example, he may consider this to be a fix; if he obtains two simultaneous radio bearings, he may consider himself to be at the intersection of these bearings.

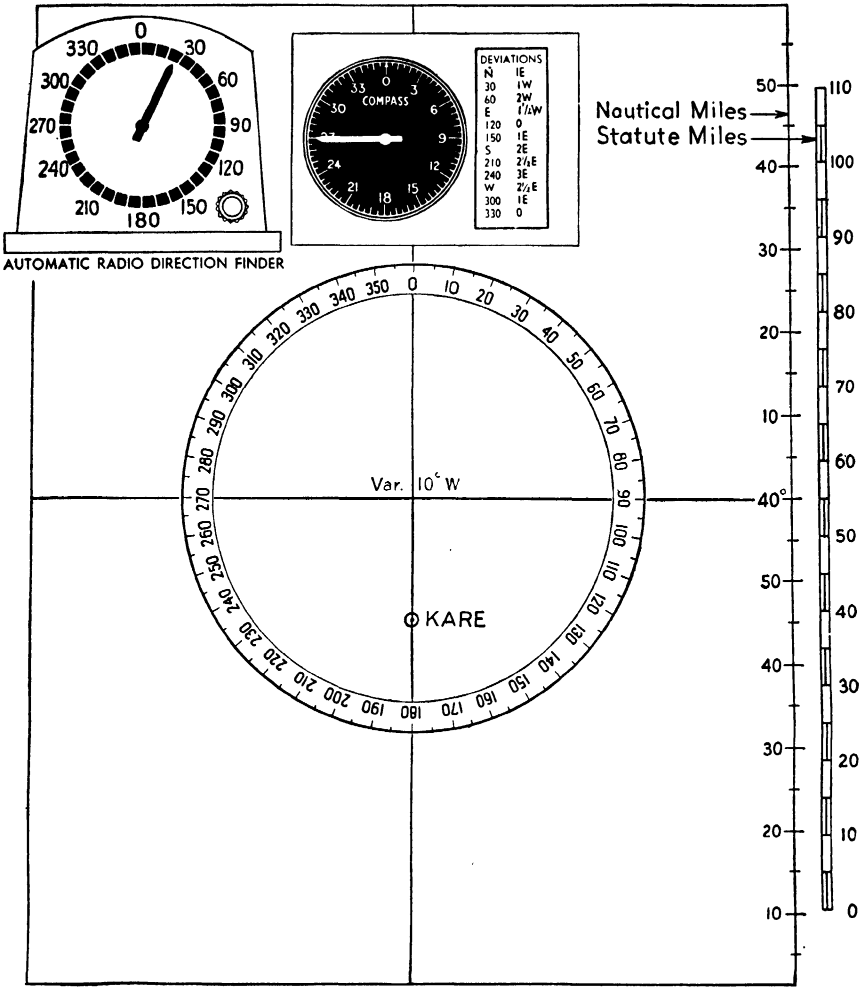


Fig. 162.—Problem 7.

The Sperry automatic dual direction finder was designed to obtain simultaneous radio bearings for this purpose. It is shown in Figs. 164 and 165.

Essentially the instrument consists of two direction finders so installed as to take simultaneous bearings. The receiving unit consists of two receivers, one of which is tuned by means of the left-hand crank, left-hand

tuning scale (lower), and left upper tuning meter. The other receiver is tuned by the right-hand tuning crank, right-hand tuning scale, and right tuning meter. Optimum tuning is indicated by maximum needle

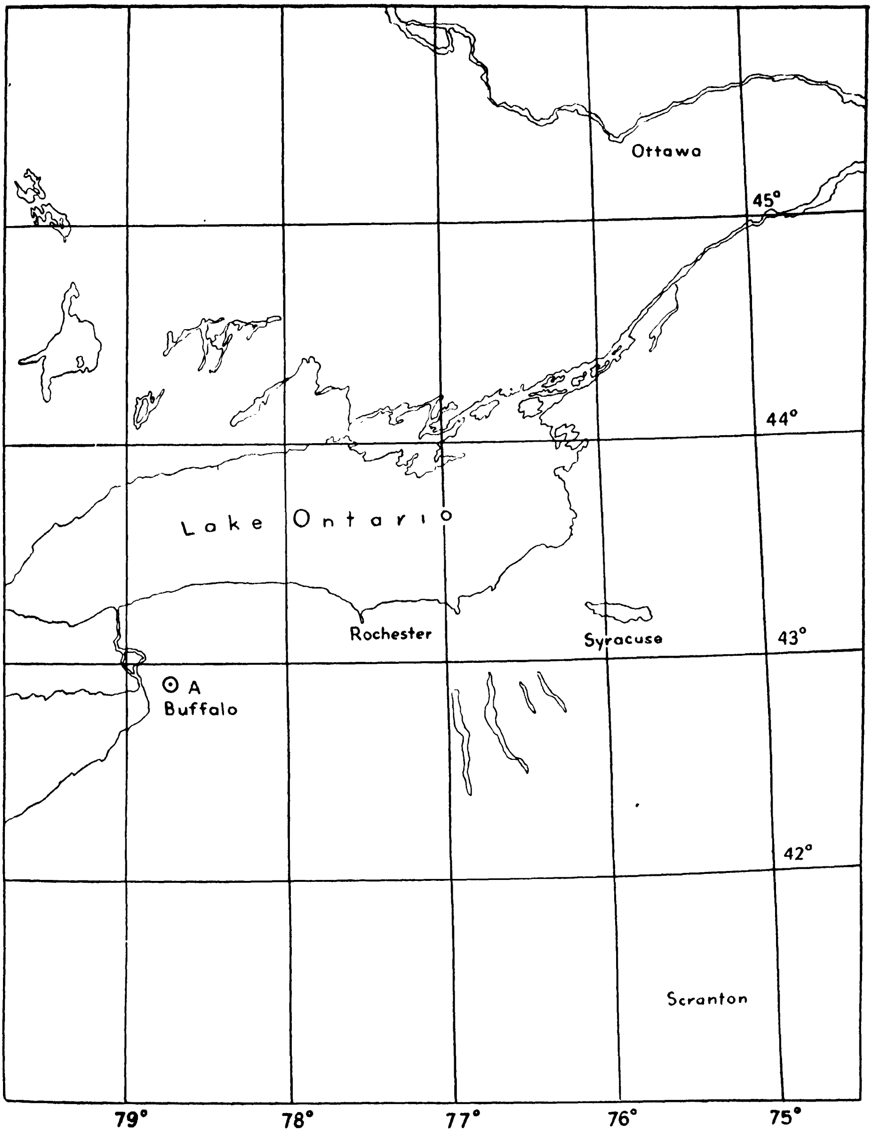


FIG. 163.—Problem 8.

swing on the tuning meters. The indicating unit has two arrows; the white arrow points to the station tuned in on one receiver, and the black arrow points to the station tuned in on the other.

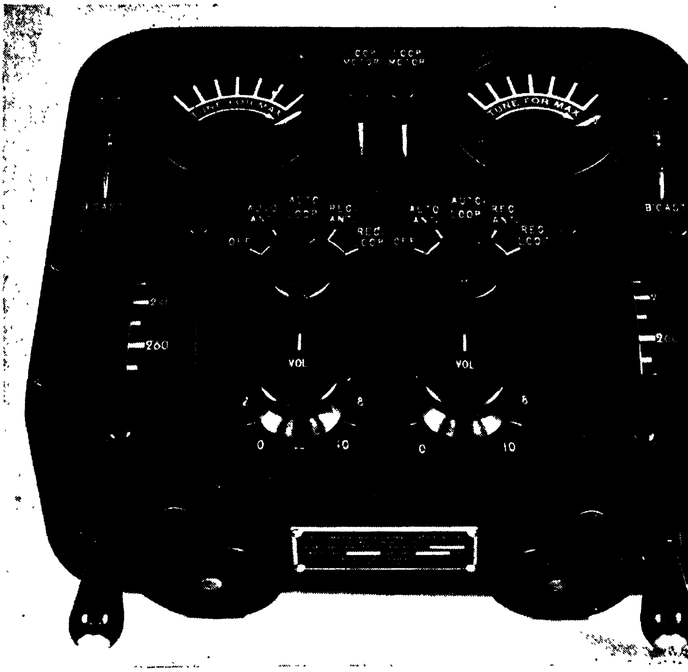


FIG. 164.—Sperry dual-direction-finder tuning unit.

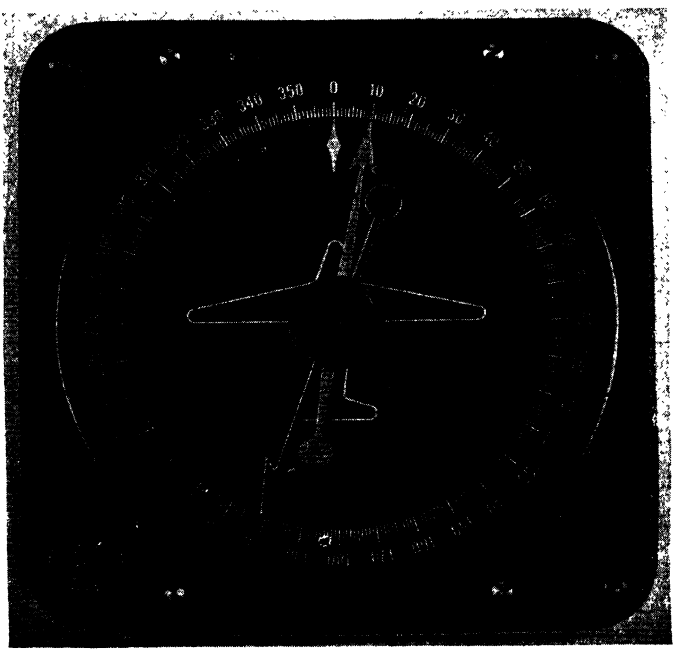


FIG. 165.—Sperry dual-direction-finder bearing indicator.

9. A pilot in the vicinity of position P (Fig. 166) at 1400 obtains simultaneous radio bearings as follows:

KNAV—260° true.

KARN—340° true.

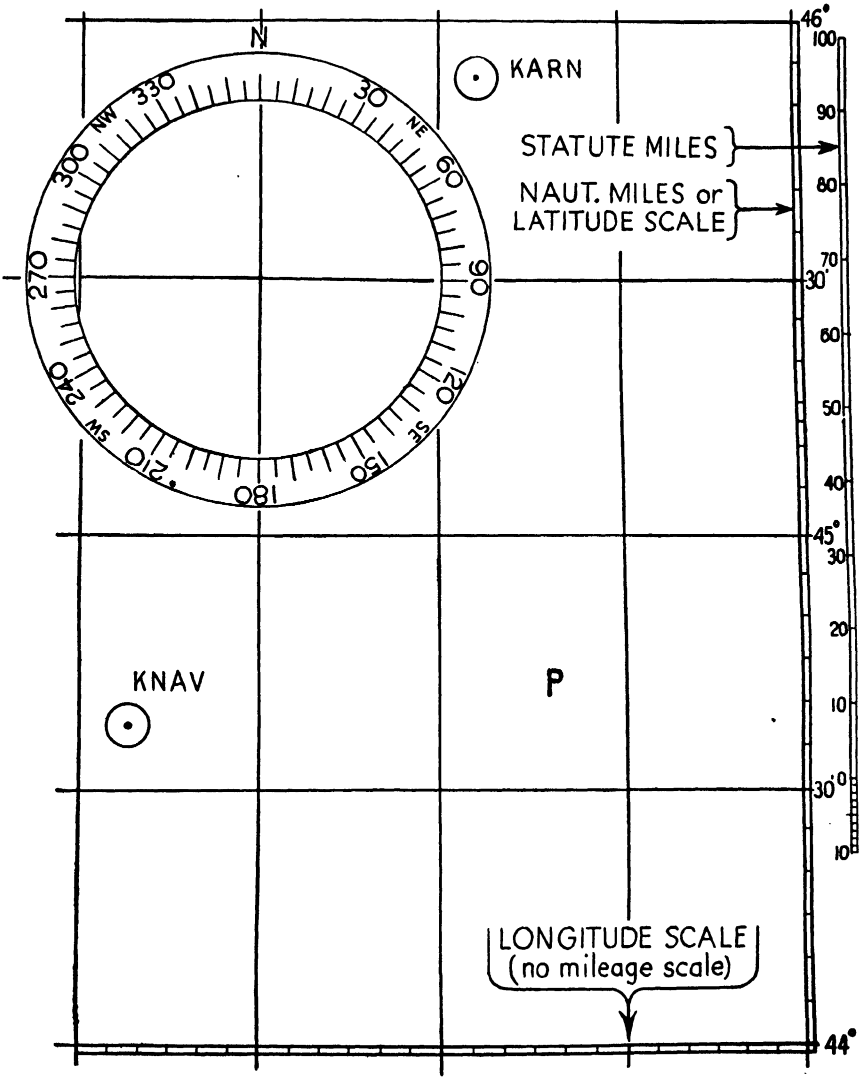


FIG. 166.—Problem 9.

Required: Plot the two radio lines of position, and show the position of the plane (the intersection of the two lines).

10. The pilot of a plane near position P (Fig. 167) obtains simultaneous bearings of the radio-range stations at A and B. A simulated dual radio direc-

tion finder is shown; the black arrow has been tuned to station B, and the compass rose has been turned to indicate the true heading of the plane.

Required: Show the position of the plane.

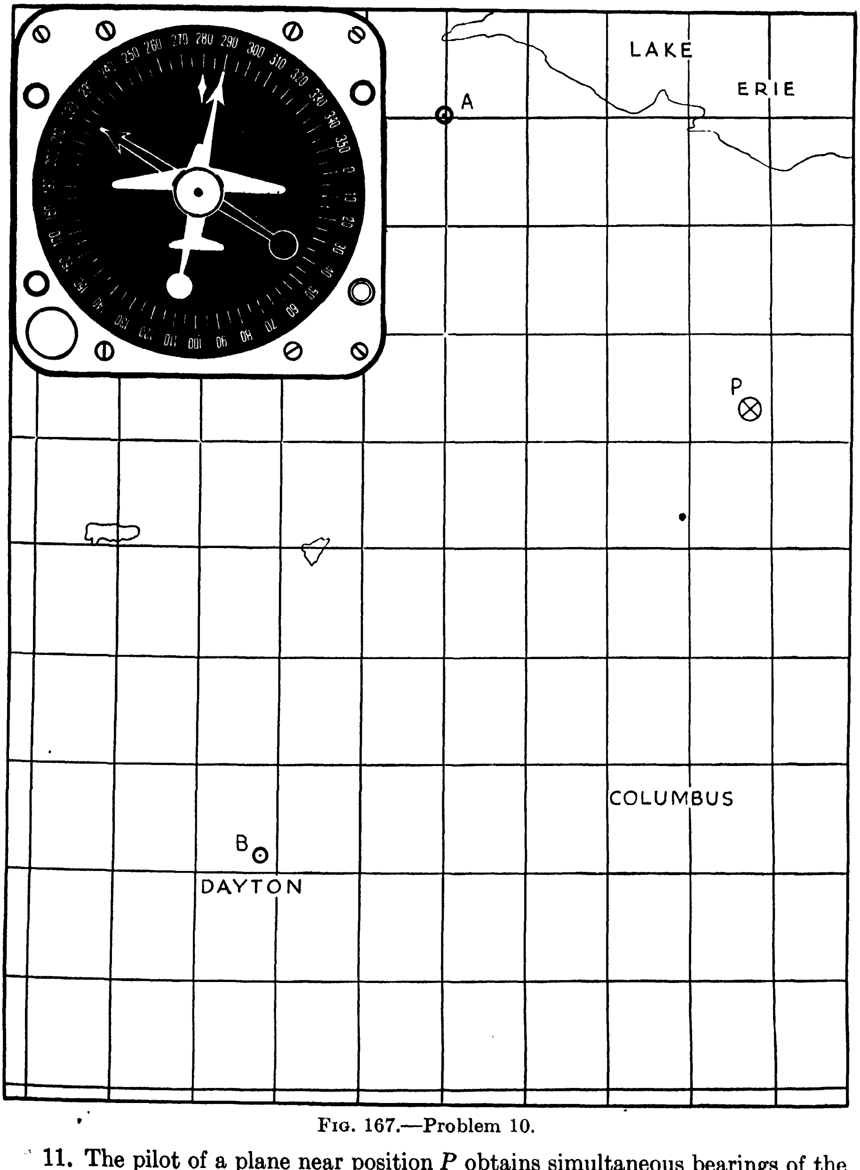


FIG. 167.—Problem 10.

11. The pilot of a plane near position P obtains simultaneous bearings of the radio stations A and B. A simulated dual radio direction finder is shown in Fig. 168. The black arrow has been tuned to station A and the white arrow to B. The compass rose has been turned to indicate the true heading of the aircraft.

Required: Show the position of the plane. What is the track from the fix to point C?

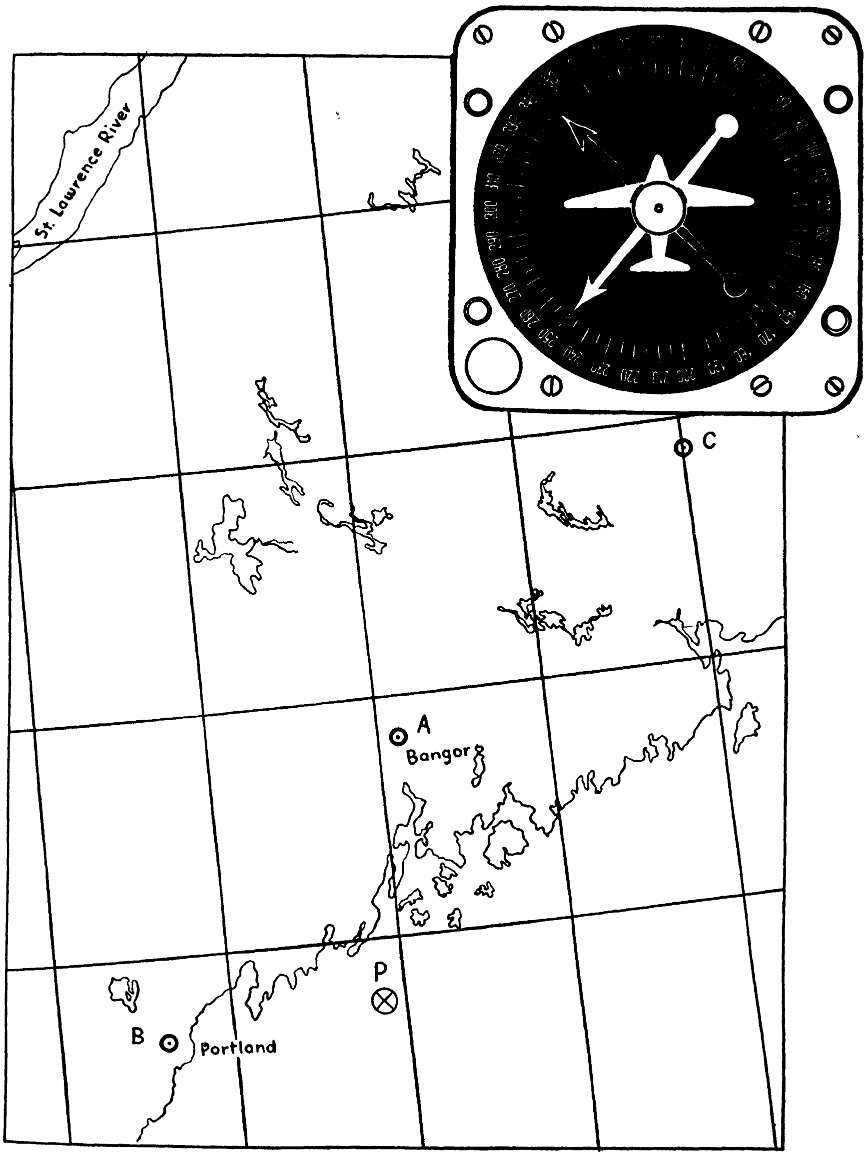


Fig. 168.—Problem 11.

12. The pilot of a plane near position P obtains simultaneous bearings of radio-range stations A and B. A simulated dual radio direction finder is shown

in Fig. 169. The black arrow has been tuned to station A, and the compass rose has been turned to indicate the true heading of the aircraft.

Required: Show the position of the plane. What is the track to point C?

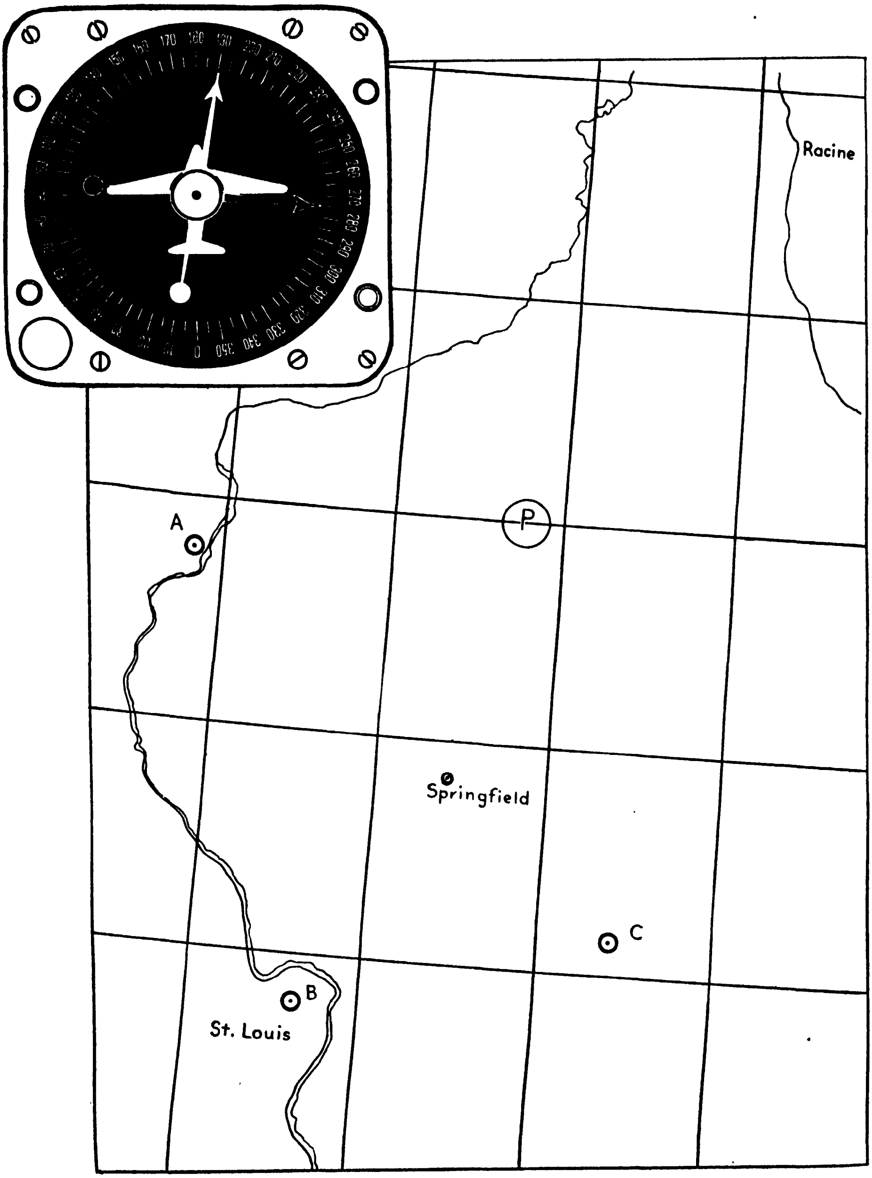


FIG. 169.—Problem 12.

The problems given so far serve to illustrate the value of two lines of position in establishing a fix. While bearings such as these result in

an instantaneous fix, it is unnecessary to take bearings simultaneously in order to acquire accurate knowledge of the plane's position. Indeed, more often than not, the second bearing line is obtained from 1 to 30 min. after the first. A fix determined by means of nonsimultaneous lines of position is called a **running fix.**

Running Fixes.—A running fix is obtained by advancing or retarding one line of position to cross with another. In Fig. 170 a plane is shown flying past a radio-range station. No radio compass was used, but by listening to the range-station transmission the pilot knew the plane crossed the northeast leg at 0900 and the southeast leg at 0915. While

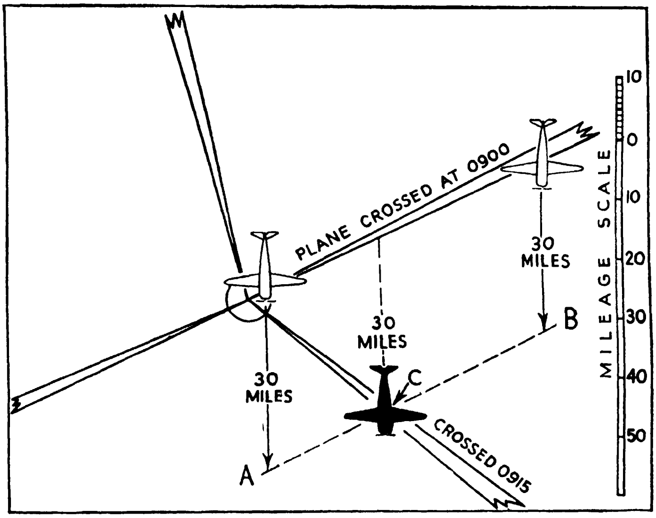


FIG. 170.—Establishment of a running fix.

the plane's position on the northeast leg was indeterminate at the time of crossing, the plane was definitely on a line of position at that time. From 0900 to 0915 a track of 180° and ground speed of 120 m.p.h. were maintained; for this reason the plane at 0915 had to be 30 miles south of some point on the first leg. The possible positions of the plane at 0915 are shown as line *AB*, a line that is everywhere 30 miles south of the northeast leg.

At 0915 the pilot knew that his plane was not only 30 miles south of the northeast leg but also on the southeast leg. He could be only at position *C*.

Notice that the first line of position was advanced in the *track* direction (180° in this case) and that the line was advanced as far as the plane had flown along this track between 0900 and 0915. If either the track or the ground speed had been in question, the resulting 0915 fix would have been only approximately correct.

Advancing Lines for a Running Fix.—The following problem will serve to show the specific steps taken in advancing a line of position: The pilot of a plane finds himself crossing a railroad track running approximately north and south. Study of his chart shows that there is only one railroad track in his vicinity and that it extends approximately north and south for a distance of many miles. His exact position is indeterminate,

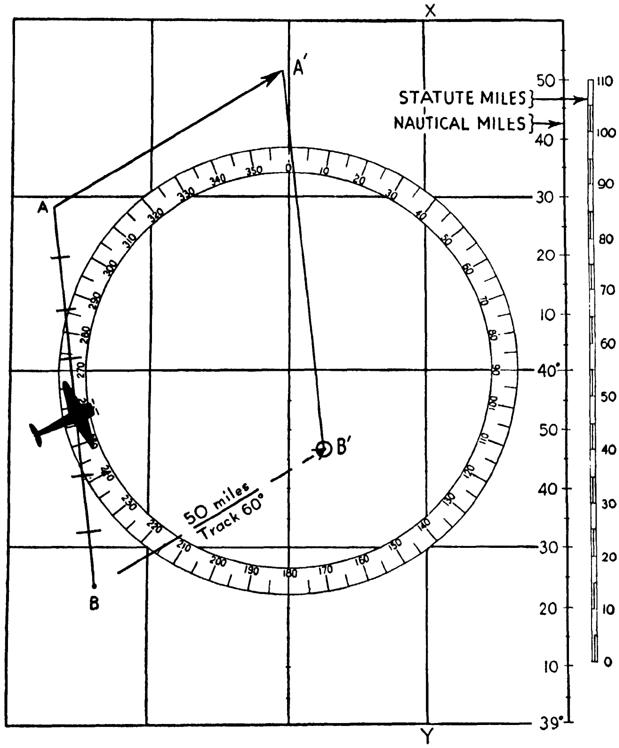


FIG. 171.—Advancing a line of position.

but he knows that he must be somewhere on the straight stretch of railroad line. The plane is making a track of 60° and a ground speed of 120 m.p.h.

Required: Show the possible positions of the aircraft 25 min. later.

Procedure: Take any convenient point on line AB (Fig. 171), such as the point B, and move it forward along track 60° for the distance (50 miles) made good during the 25-min. interval. Spot in this advanced position, and label it B'. Redraw the original line AB parallel to itself through the position B'. The point A or any point along the line AB could have been selected for this purpose. The line $A'B'$ is the advanced line of position and contains all the possible positions of the aircraft

25 min. after having crossed the line *AB* on track 60°, ground speed 120 m.p.h.

PROBLEMS

1. A plane flies over a section of the coast line labeled *AB* (Fig. 172). A track of 124° and a ground speed of 120 m.p.h. are being made. Show the possible positions of the aircraft 26 min. later.

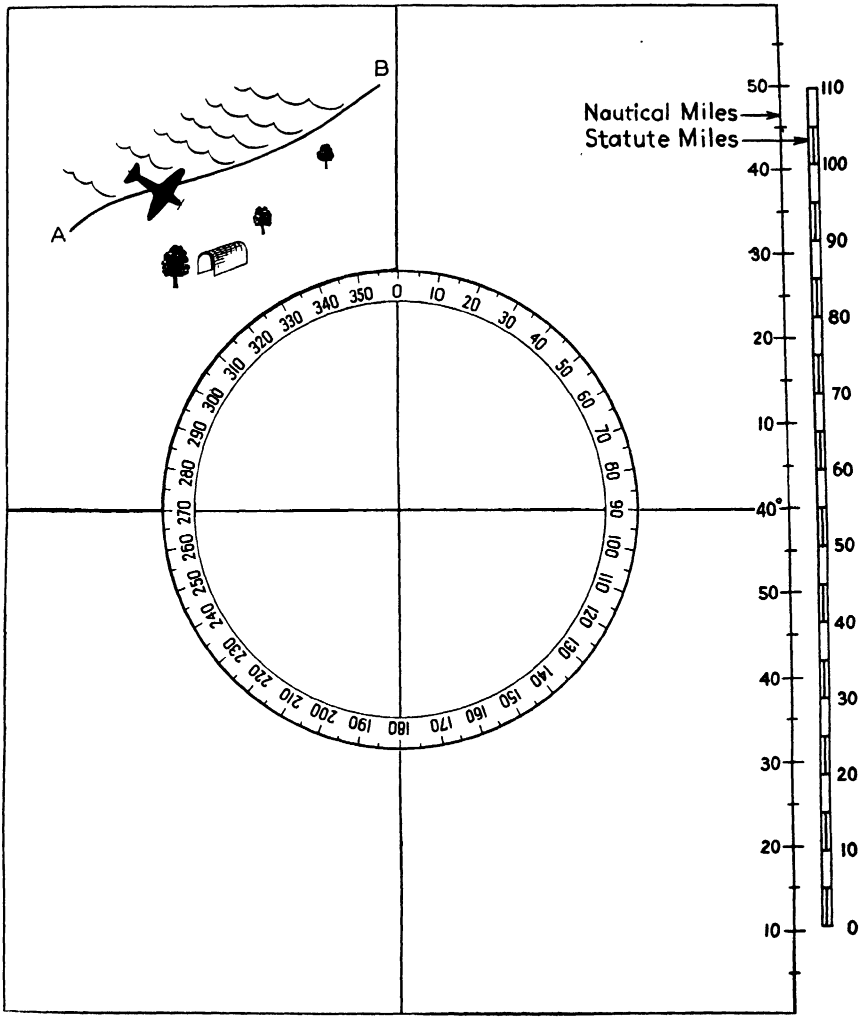


Fig. 172.—Problem 1.

Note: Precise navigation calls for duplicating the curvature of the line *AB* in the advanced position.

2. A plane flies over a section of a railroad line (Fig. 173). A track of 145° and a ground speed of 105 m.p.h. are being made. Show the possible positions of the aircraft 35 min. later.

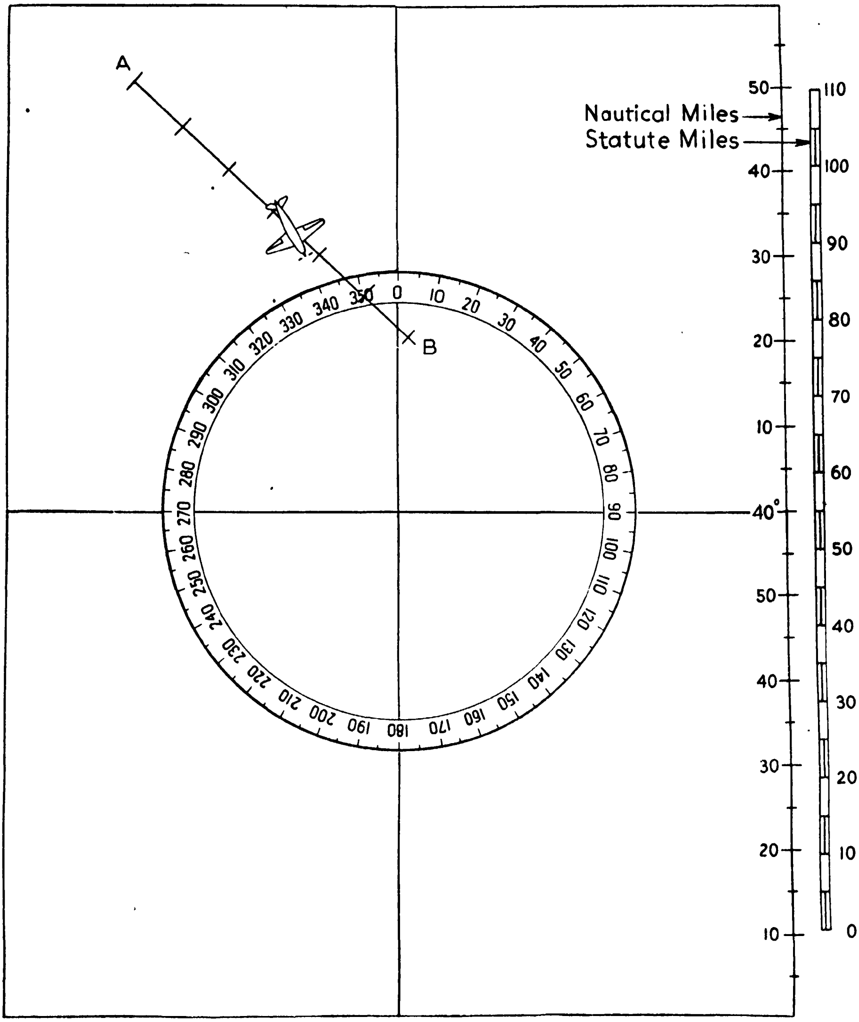


FIG. 173.—Problem 2.

3. A plane passes through the southeast leg of a radio-range station (Fig. 174). A track of 302° and a ground speed of 160 m.p.h. are being made. Show the possible positions of the aircraft 10 min. later. If the pilot now finds himself crossing the southwest leg of the same station, how far away from the station is the plane?

4. By means of his radio direction finder the pilot of a plane obtains a true bearing of north on radio station WXYZ (Fig. 175). His plane is making a

track of 210° and a ground speed of 150 m.p.h. Twenty-three minutes later he obtains a true bearing of 302° on radio station KXXY.

Required: Show the position of the plane at the time of taking a bearing on KXXY.

NOTE: Advance the first radio bearing (line of position) for the distance made good over the ground in 23 min. The track along which this distance is to be measured is 210°. The intersection of this advanced line with the second radio bearing (line of position) will show the location of the plane.

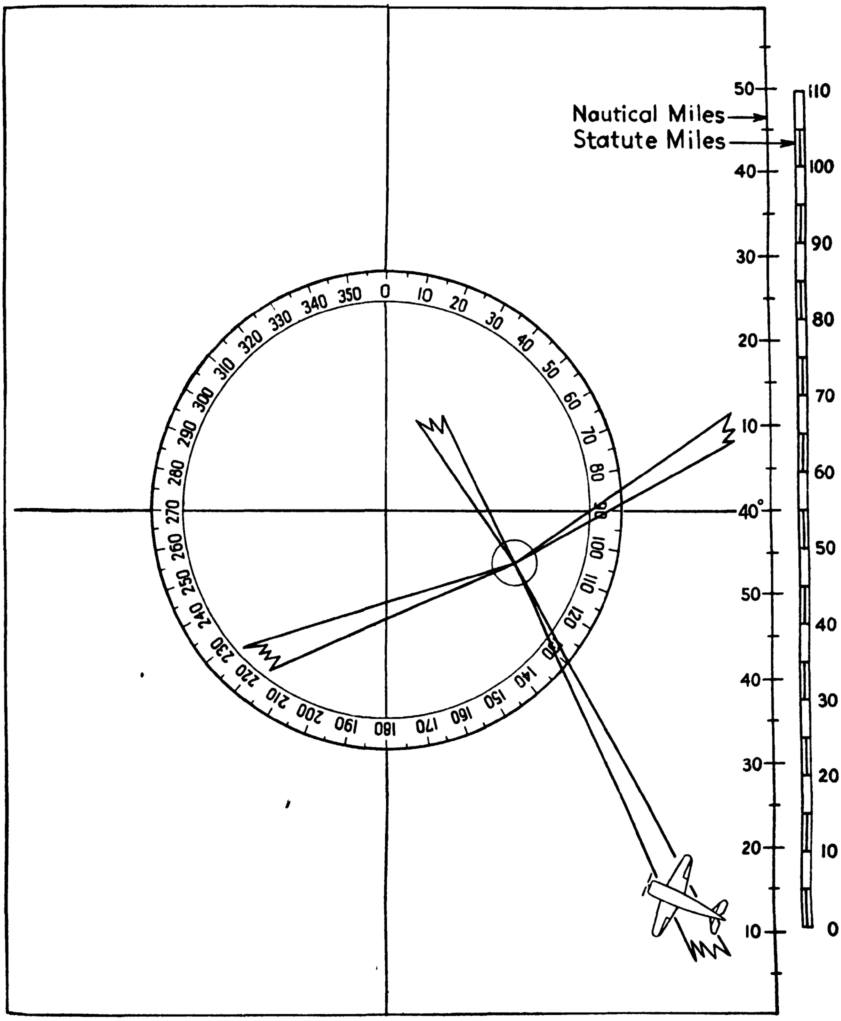


FIG. 174.—Problem 3.

5. A plane passes over a known railroad track AB (Fig. 176) at 0930 and continues on making a track of 317° and a ground speed of 120 m.p.h. At 1002

the pilot finds himself passing over the coast line *CD*. Show the location of the plane on the coast line at 1002.

6. At 1135 a plane crosses the northeast leg of radio-range station *A* (Fig. 177) and continues on making a track of 355° and a ground speed of 150 m.p.h.

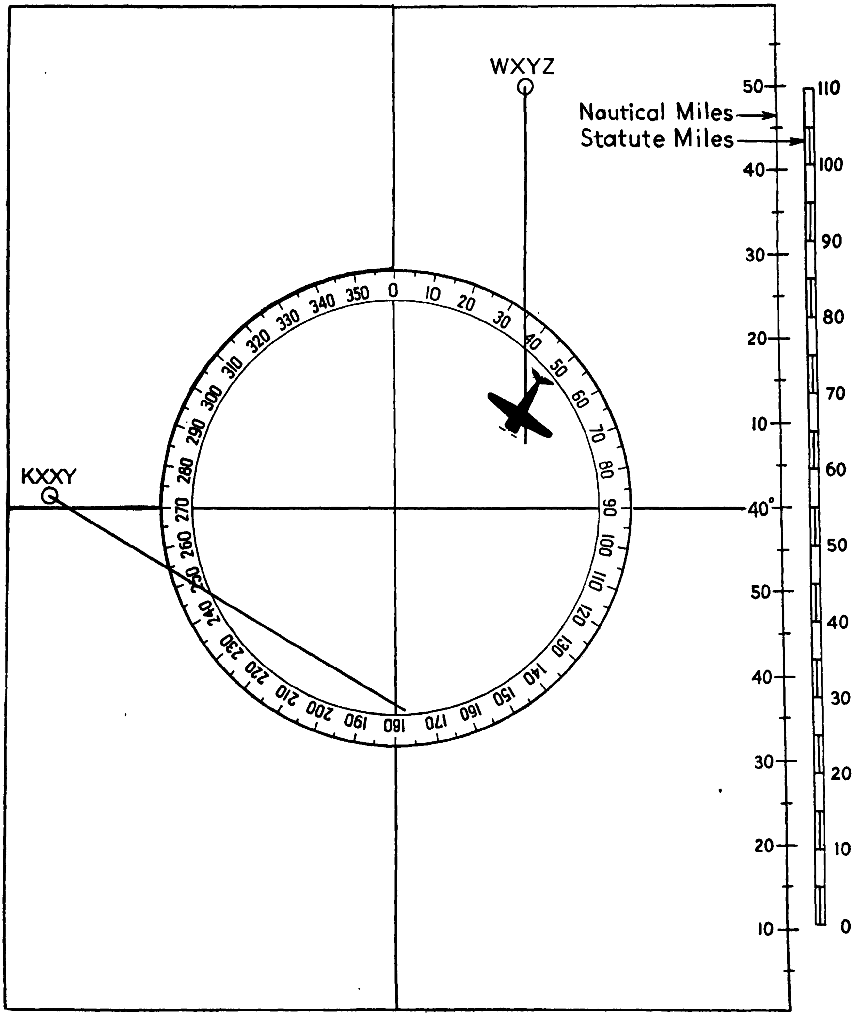


FIG. 175.—Problem 4.

At 1203 the plane crosses the southeast leg of radio-range station *B*. Show the position of the plane at 1203. Where would the plane have been at 1203 if a track of 355° and a ground speed of 120 m.p.h. had been maintained?

NOTE: Had the pilot been certain of his track but uncertain as to his ground speed within the limits just given, he would have had to recognize the possibility of his

being anywhere on the southeast leg of radio-range station *B* between the two positions plotted.

7. At 0622 a pilot obtains a true bearing of 135° on radio station KARM (Fig. 178). The plane maintains a track of 195° and a ground speed of 240

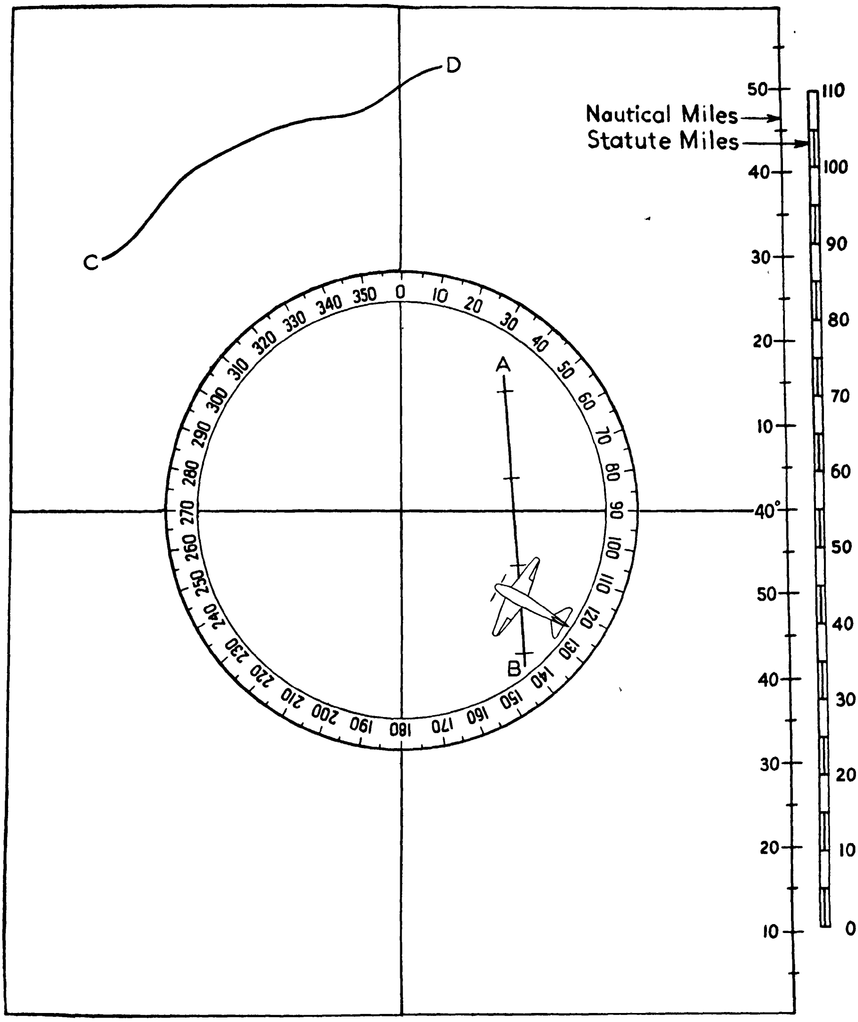


FIG. 176.—Problem 5.

m.p.h. At 0634 the pilot obtains a 250° true bearing on station KNAV. Show the position of the plane at 0634.

A question must have come into the student's mind as to just how the pilot knew his track and ground speed in the problems just given. In previous chapters several means of closing the triangle of velocities

were discussed, and it should be constantly borne in mind that the solution of the triangle furnishes information as to track and ground speed made good.

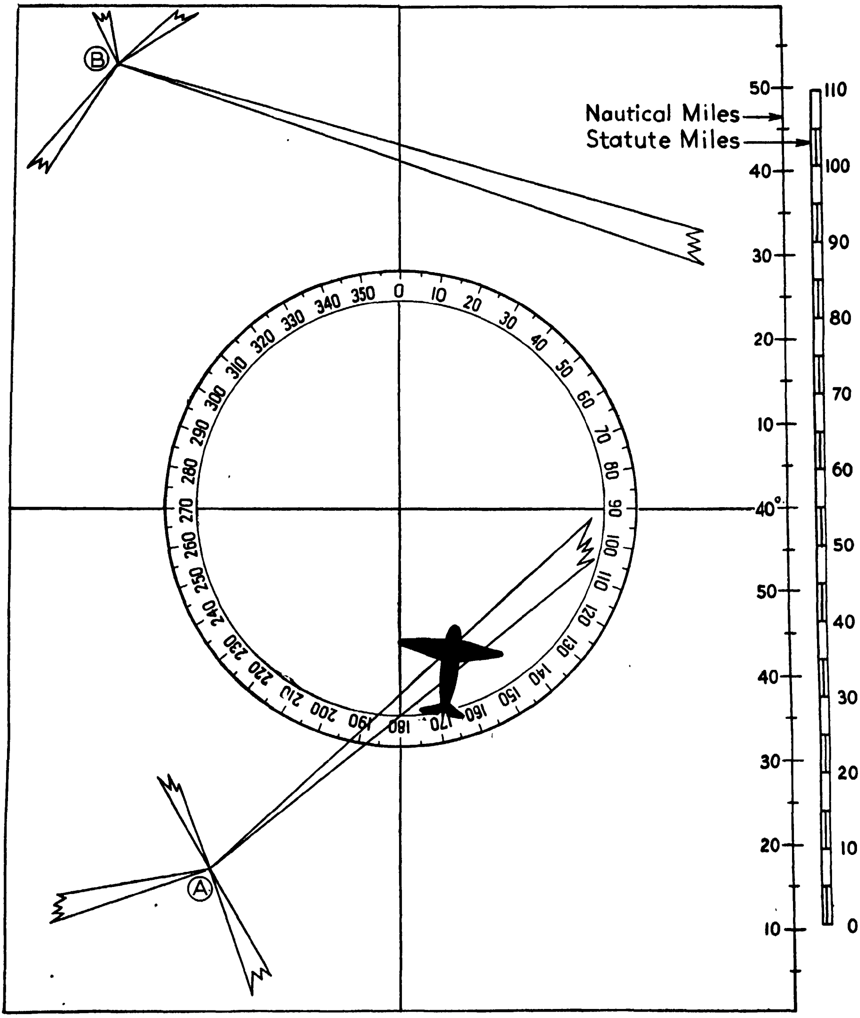


FIG. 177.—Problem 6.

The point should be reemphasized here that the accuracy of fixes obtained through advancing lines of position depends on the navigator's knowledge of track and ground speed being made good. This is not to say that an erroneous assumption of ground speed produces an exact corresponding error in the resulting line of position. If the navigator does not know, for example, whether the ground speed is 150 or 160 m.p.h.

and wishes to advance a line for an 8-min. run, he would in the first instance advance the line 20 miles and in the second instance 21½ miles.

In Fig. 179, a plane left station *A* at 1500 and headed toward station *X*. The angle at which the plane crossed the northern leg of station *X*

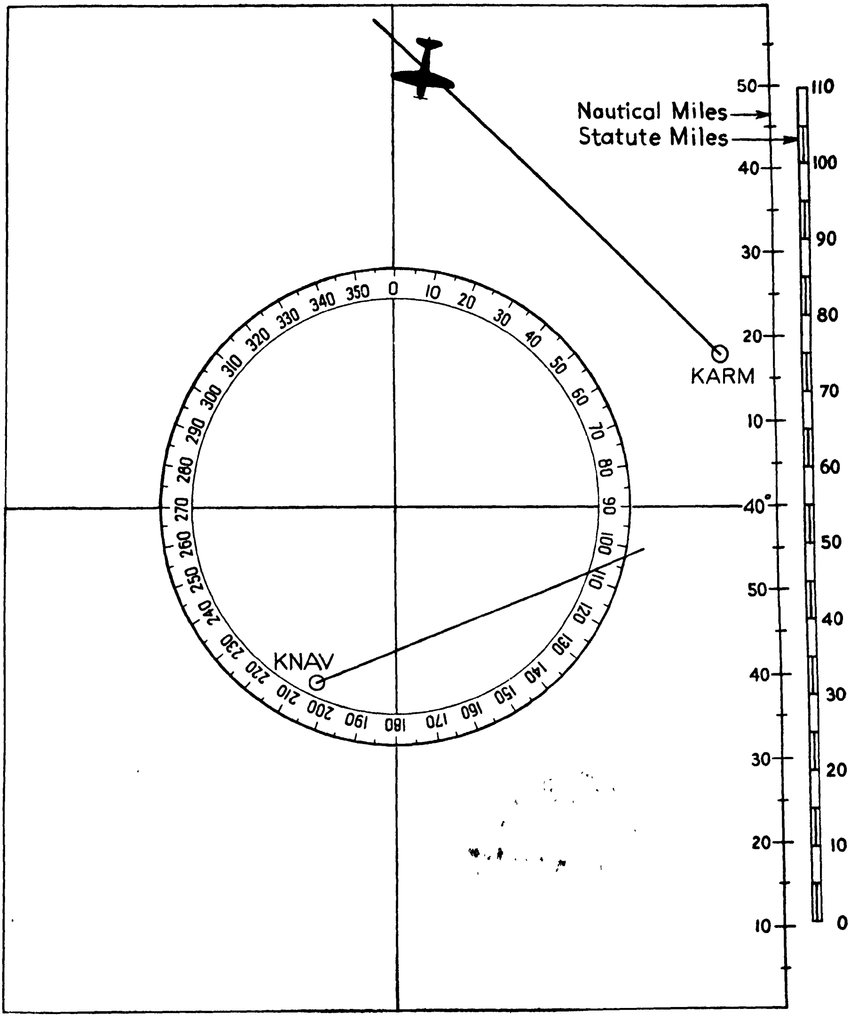


FIG. 178.—Problem 7.

was too acute to permit ground-speed determination; a slight error in estimating the track made good would materially alter the estimated position of crossing the leg. At 1535, however, the plane crossed the east leg, and it crossed at such an angle that the plane could have been at any point, such as *B*, *C*, or *D*, without materially changing the meas-

ured distance from A. Thus the east leg of the range station X becomes a **speed line** and by its use the ground speed becomes known.

Problem: Assume that the plane crossed the east leg at position E (Fig. 179), and plot the running fix. Next assume that the plane crossed at the fix, and

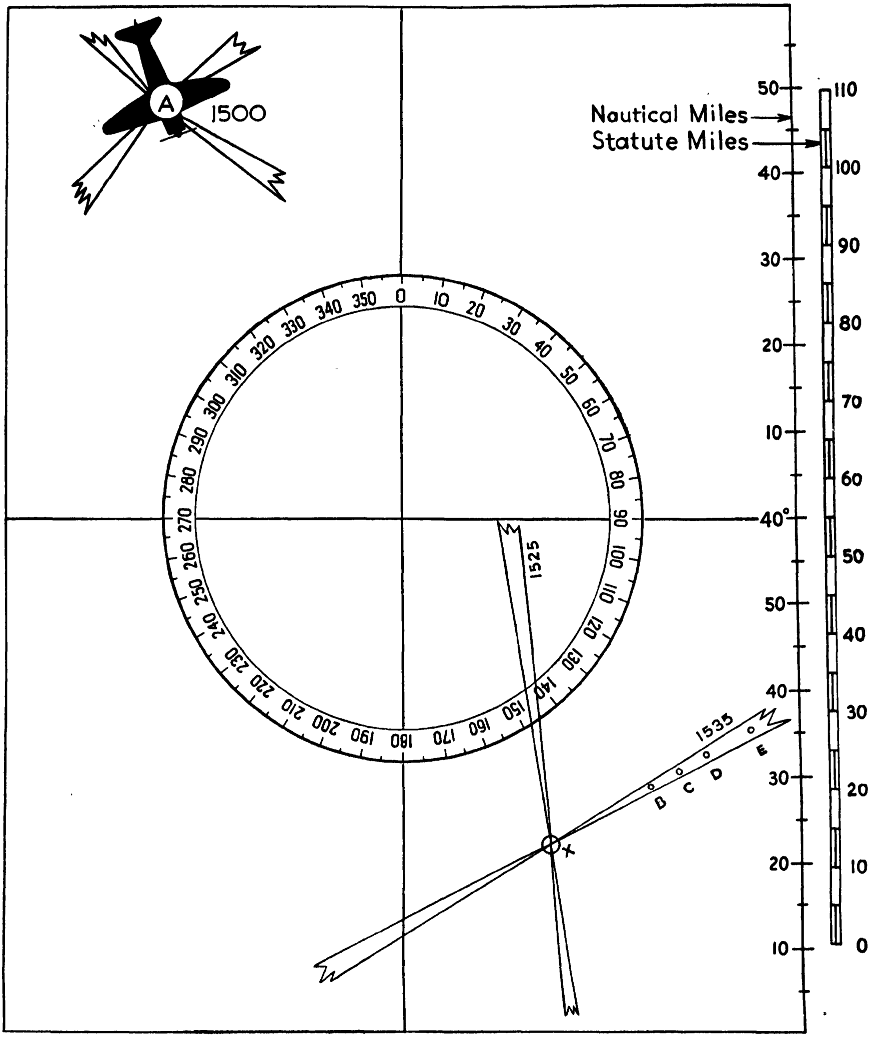


FIG. 179.—Problem in establishing a running fix.

rework the problem with the more approximate track and ground speed thus established. Does the reworked fix differ materially from the first?

The error introduced in a running fix through lack of knowledge of the ground speed can be reduced by advancing the line most nearly

parallel to the track. A line of position exactly parallel to the track advances along itself. It may be stretched sufficiently to intersect the speed line without being moved out of position. To a lesser extent this is true of lines that nearly parallel the track, as shown in Fig. 180. The navigator obtained a track line of position at 1500 and a speed line at 1520. Fix *A* results from advancing the track line at the rate of 120 m.p.h.; fix *B* results from advancing the same line at the rate of 180 m.p.h. In spite of the great difference in assumed ground speeds there is little difference in the two possible positions of the plane at 1520.

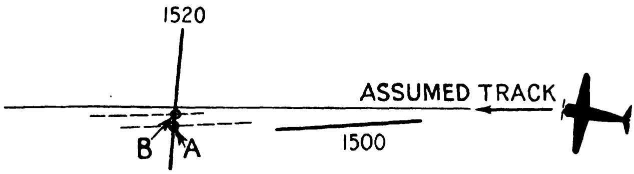


Fig. 180.—Moving a track line to obtain a running fix.

If, under similar circumstances, a speed line were advanced to intersect a track line, there would be wide disagreement in the two possible fixes. Fix A in Fig. 181 results from advancing a speed line at the rate of 120 m.p.h.; fix *B* results from advancing the same line at the rate of 180 m.p.h. In this instance neither the 1500 nor the 1520 position of the plane becomes accurately known, and determination of the past wind becomes impossible.

When a running fix is to be obtained, it is always good practice to obtain the track line of position *first* and the speed line *last*. This ensures (1) that the track line may be advanced with a minimum of error and (2) that the resulting fix will be as recent as possible. In connection with this, it should be remembered that, though the plane's *average* ground speed may be obtained by using the time and distance from the last fix, there is seldom any assurance that the plane made this ground speed during the interval required to obtain the last fix.

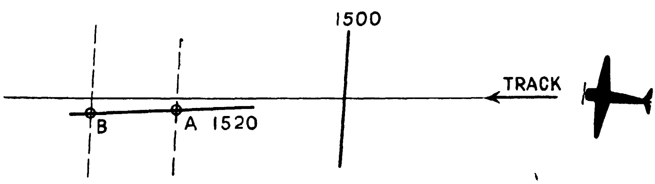


Fig. 181.—Moving a speed line to obtain a running fix.

In the case shown in Fig. 181, the navigator should not have moved the 1500 speed line. By so doing he failed to establish either the 1500 or the 1520 position of the plane. The 1520 track line should have been

retarded (using either ground speed) and possible 1500 fixes would have resulted as shown in Fig. 182. Either of these fixes is sufficiently accu-

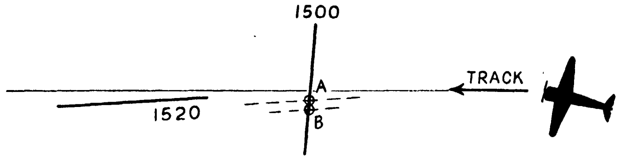


FIG. 182.—Retarding a track line to obtain a running fix.

rate to permit determination of the past wind, and with this information a reasonably reliable 1520 position could have been ascertained.

Use of Single Lines of Position.—The use of single lines of position as an aid in the establishment of either track or ground speed has just

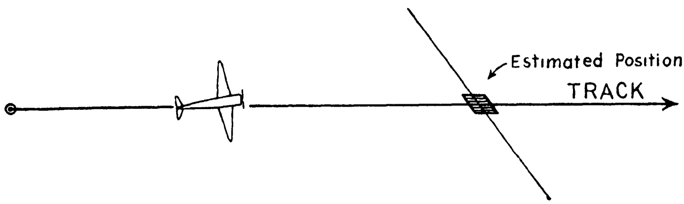


FIG. 183.—Estimating position on a line of position—track known.

been discussed. Careful selection of radio stations is all that is required to establish either the one or the other. There may be occasions, however, when the only line of position available fails either to cross the track

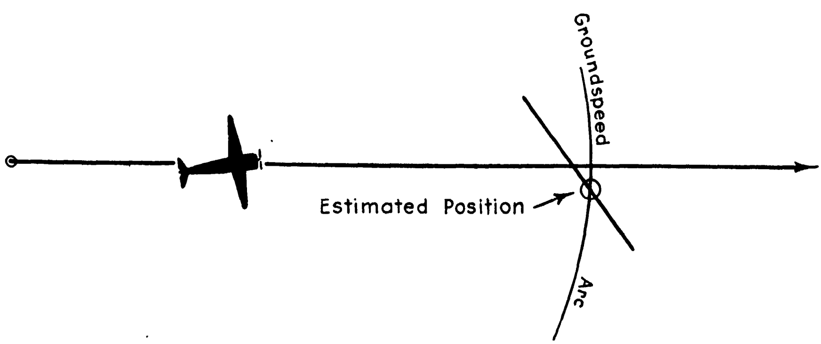


FIG. 184.—Estimating position on a line of position—ground speed known.

at right angles or to parallel it. There are several methods of estimating the plane's position on such a line, the method used depending on the navigator's knowledge of certain factors.

He may have a good idea of the track being made through more or less continuous drift observations. In such a case the known track should be laid down from the last known fix, and the intersection of this track line and the line of position must be considered the most likely position of the plane.

He may, on the other hand, have a good idea of the ground speed made good from the last fix. If his knowledge of ground speed is better than his knowledge of track, an arc equal to the distance made good since the last fix should be swung from that point until it crosses the line of position. This intersection should be considered the most likely position of the plane.

If his knowledge of the one is no better than the other, he should locate his plane's position on the chart (independent of the line of position) and drop a perpendicular from that position to the line. In so doing he will reconcile his best former assumption of position with the new line on which he knows the plane must be located.

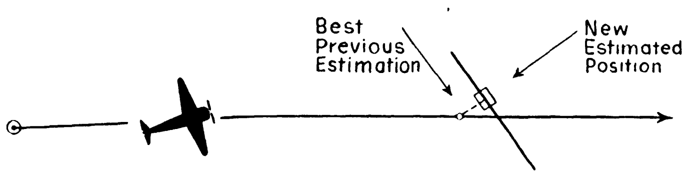


FIG. 185.—Estimating position on a line of position—track and ground speed uncertain.

Application of Tolerances to Radio-bearing Lines of Position.—Navigation is by no means an exact science. The navigator is expected to arrive at an exact destination, but to do so he is obliged to use extremely variable and uncertain flight data. Face readings of panel instruments are seldom true. Although methods of correcting these readings were set forth in considerable detail in Chap. IV, the point was stressed that even when corrected these readings could not be considered accurate to the *n*th degree. The degree of accuracy of radio lines of position is likewise subject to question. Failure to take into consideration the probability of error may lead the inexperienced navigator into serious errors of judgment.

The accuracy of radio lines of position is dependent on several factors: physical stability of the observer, accuracy of the radio direction-finder calibration, accuracy of the compass used in conjunction with the direction finder, strength of signal on which bearings are taken, and static level.

Accuracy of Bearings Taken from Ground Radio Compass Stations.—The United States Navy maintains radio compass stations at numerous places along our seaboard. These stations, manned by experts, have

been operating for years, and so excellent is their calibration that bearings taken on approaching ships are furnished in degrees and tenths of degrees. Needless to say, the equipment is permanently and rigidly installed, and the bearing taker is not handicapped by having to work on an unsteady platform.

On one occasion when the author's ship was drifting slowly off the Delaware Capes, it was possible to determine the set and drift of the current by means of these bearings. The ship, however, was only about 20 miles from the radio compass station, and its transmitter (on which the bearings were taken) was rated at a full kilowatt. There was apparently no error in the bearings.

Accuracy of Radio Bearings Taken from Ships.—Under circumstances similar to those described in the preceding paragraph, when approaching Boston the author took a series of radio bearings (using the ship's direction finder) and could not vouch for their accuracy within 2°. These bearings were taken in conjunction with a magnetic compass instead of a true compass rose permanently mounted on shore. While the error of this compass was well known, its movement was somewhat sluggish and its indications could not be considered reliable within 1°. The ship's radio direction finder likewise was calibrated, but not to a point where the loop indications could be termed accurate within 1°.

Accuracy of Radio Bearings Taken from Planes.—Provided that the signal strength is adequate, bearings taken from shore stations should be more accurate than bearings taken from aircraft. This presupposes the use of modern equipment and highly trained personnel in each case. In spite of this, the author has a distinct preference for bearings taken from a plane. A bearing so taken may look questionable when plotted on the chart, but there is an opportunity to discuss its probable accuracy with the radio officer. Was the signal strength sufficient? Was the bearing sharp or broad? Did it appear to shift? Did it appear to fade? Was the magnetic compass steady? These questions arise in the mind of the navigator whenever radio bearings are used. If uncertainty exists regarding those taken from a plane, a series of bearings may be taken and their average used to advantage.

On one occasion, when the author's plane was approaching New York, the signal strength of the shore transmitters was weak and at times faded out altogether. The air was turbulent, and the compasses oscillated through an arc of nearly 20°. Under this trying condition, an average of approximately 40 compass readings and 40 radio bearings were taken over a period of 3 min. In averaging these bearings and compass headings, the author attempted to eliminate any gross error that might have resulted from a single reading. The result was not a first-class bearing, but it was a bearing on which some degree of reliance could be placed.

Naturally, the bearings improved as the plane approached the station. Even under favorable conditions it is good practice for the navigator and radio officer to work together for a period of at least 1 min. when taking bearings in order to obtain average readings of their respective instruments.

But even when this is done the compass reading and the direction-finder bearing may each be 1° in error. Then, too, before the bearing may be plotted as a true bearing, the total error of the compass must be applied, and this may be accurate only to within 1°. There may be times when the error in reading the compass may be balanced by the error in reading the direction finder. Likewise, an error in the tabulated compass deviation may be offset by an error in the direction-finder calibration, but the possibility of these errors combining must not be overlooked. Prudence, in fact, demands that this assumption be made, and the navigator will do well to take this possibility into consideration at all times. This may seem unimportant in flying over territory where such a cumulative error could result in no serious mishap; but it is the duty of the navigator to consider all possible positions of the aircraft, and the habit of considering possible errors in bearings should be acquired early.

When 60 miles separates transmitter and radio direction finder, an assumed error of 1° in a radio line of position demands an assumption that the plane may be 1 mile either side of that line. When 120 miles separates the two, an error of 1° results in a possible off-track error of 2 miles. If an error of 5° be assumed when the plane is 300 miles from the station, the plane may be 25 miles either side of the radio line of position.

The student should not gather the impression that such bearings are altogether valueless. When used with due regard to their limitations they may prove to be of real value, but should the possibility of error be overlooked they may prove most misleading. At a distance of 300 miles an experienced navigator rather expects the radio bearings to jump back and forth across the track. As the plane approaches the station, the bearings will jump back and forth considerably less (owing to the decreased distance) even though the navigator assumes the existence of the same error in them.

As stated before, when a large number of radio bearings are taken, certain errors may be expected to average out. It is hardly conceivable that the radio officer will always make an error in the same direction, and it is unlikely that the compass headings will always be off the same amount in the same direction each time a bearing is taken. Thus, when a *series* of bearings is taken (even when the plane is at a considerable distance from the transmitter) a certain amount of reliance may be placed on their average.

PROBLEMS

1. A plane in the vicinity of position P obtained a relative radio bearing of 320° on radio station KABC. At that time the plane was headed 270° true.

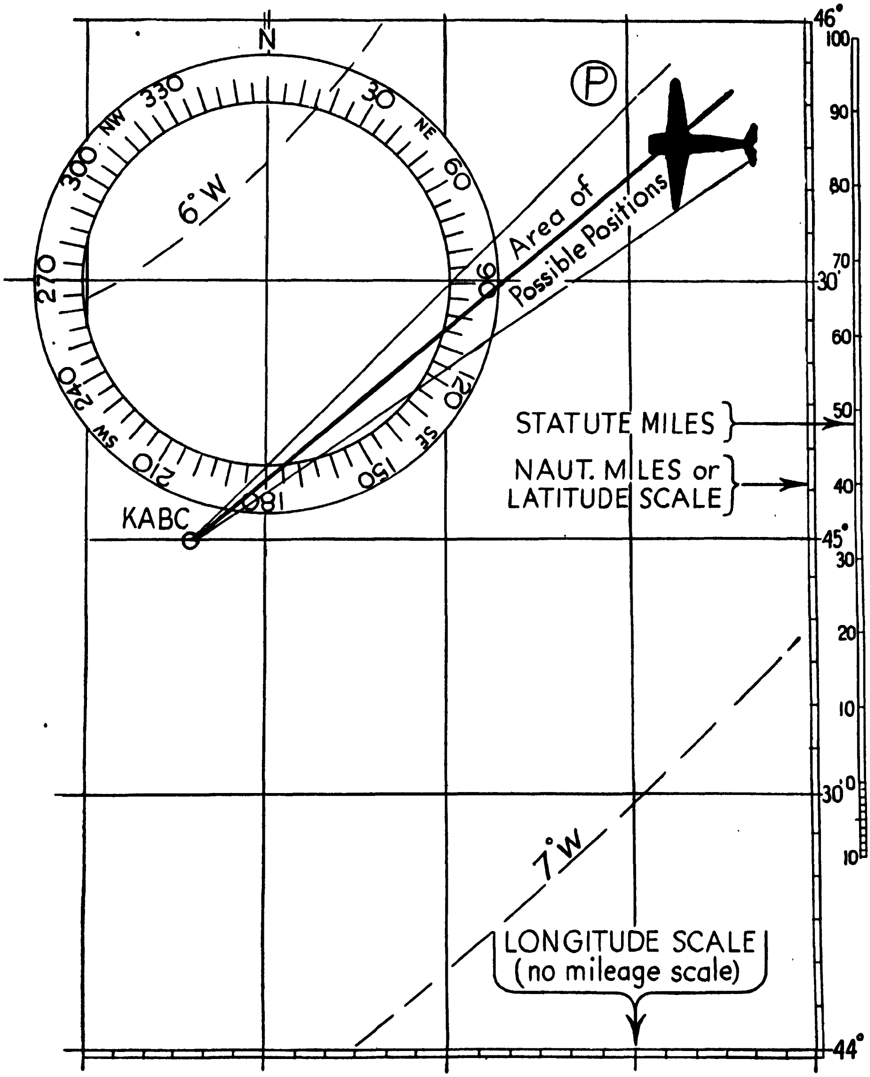


FIG. 186.—Application of tolerance to a radio line of position.

An error of 3° in the radio bearing, 1° in the compass heading, and 1° in the deviation was assumed.

Required: Show the area in which the plane could be located.

Procedure: Plot the radio bearing (assuming none of the errors mentioned above). Plot another bearing 5° less and a third bearing 5° greater than the original. This problem is illustrated in Fig. 186.

2. A plane in the vicinity of position *P* (Fig. 187)[1] is advised by radio that it bears 80° true from station KABC.

Required: Assume an error of 2° in the bearing, and show the area in which the plane could be located.

3. A plane near position *P* (Fig. 188)[1] is advised that it bears 90° true from station KABC and 160° true from station KBCD. The bearings were taken simultaneously at the request of the pilot.

Required: Show the area in which the plane could be located, allowing a 2° tolerance on each bearing.

4. At 1415 a magnetic bearing of 350° is obtained on radio station KBCD. At 1435 a magnetic bearing of 260° is obtained on radio station KABC. The instrument panel is shown on the chart. The 1400 position of the plane is shown at *X* (Fig. 189).[1]

Required: Assume that the values shown on the instruments were maintained throughout the period involved. Assume 3° tolerance in each line. Show the area containing the possible positions of the aircraft. What wind is acting on the plane? What will the compass heading be to make track 280° from the 1445 position of the plane?

Use of Fixes.—There will be times when the mere establishment of a fix will in itself be of extreme importance. Such would be the case if it

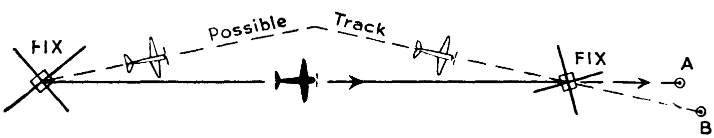


FIG. 190.—Possible track between fixes.

showed the plane to be dangerously close to high terrain or over unfriendly territory. In routine flying, the establishment of a fix is of equal importance. Not only does it show where the ship is located—it also supplies information regarding the track and ground speed made good, as in the last problem. This is the information the navigator must have at hand in order to determine the average force and velocity of the wind that has been acting on the plane. It is through knowledge of the past wind (and of the wind forecast for the trip) that he arrives at a decision as to what allowance to make for the wind in the next leg of the flight. In the absence of more specific information or knowledge of the winds ahead, the navigator may—with caution—continue using the past wind. Since on long flights the wind may shift radically several times, this method of "feeling" one's way is not to be recommended. If it is to be used with

[1] Figures 187 to 189 are contained in the pocket in the back of the book.

reasonable success, it calls for frequent and positive determination of the plane's position.

Study of Fig. 190 will emphasize the point that, while two fixes may show the plane to have proceeded in a straight line, it may actually have been making an entirely different track when the second fix was obtained. On the basis of performance between fixes the navigator may assume his plane to be at position *A* when it is actually at *B*.

Use of a Fix in Passing an Obstruction.—The application of tolerances to lines of position becomes all the more necessary if the fix is formed by two lines crossed at an acute angle. Under this condition the area of possible positions becomes diamond-shaped rather than square, and the distance separating possible positions at the corners becomes large.

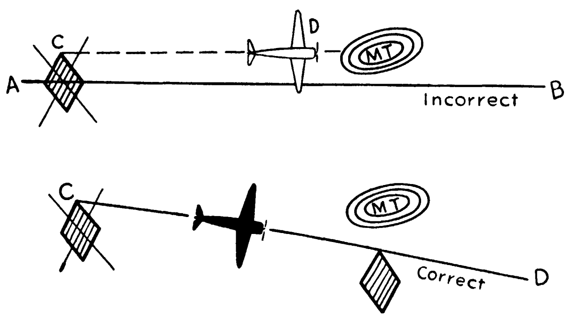


FIG. 191.—Application of tolerance to lines of position—passing an obstruction.

It would be poor judgment to attempt to pass a high mountain by following a track drawn from the center of such a fix. To be sure, if the plane happened to be at the center of the fix, it would get by safely; if, however, it was actually located at the upper corner of the area of possible positions, it would crash. The correct procedure to follow is shown in Fig. 191. If the plane is to pass south of the mountain from such a fix, the navigator must assume his plane to be at *C*, the most critical point, and lay a track from there—not from the center of the fix. It may develop later that the plane, at the time of taking the fix, was actually in the lower part of the shaded area. This may have resulted in flying considerably off track and in the loss of some time. Nevertheless, it is the duty of the navigator to consider all possible positions of his plane. In this instance, it was his duty to see that the whole area of possible positions—not just the center—moved past the mountain.

Radio Bearings and Mercator Charts.—Radio bearings travel from point to point over the shortest possible route, and this, on the face of the earth, is a great circle. On a Lambert chart a great circle appears as

a straight line. On a Mercator chart, such as that used in ocean flying, the great circle appears as a curved line.

In Fig. 192 the arc shows how a radio signal transmitted from T travels. Its direction of travel as it crosses the meridian of receiver R is shown by the angle A. A radio direction finder tuned to transmitter T would indicate that the station bore 55°. The signal does come from that direction, but it has followed a curved path. The transmitter is located at the end of that curved line and not at the end of a line drawn 55° from the receiver's meridian. If the 55° true bearing obtained with

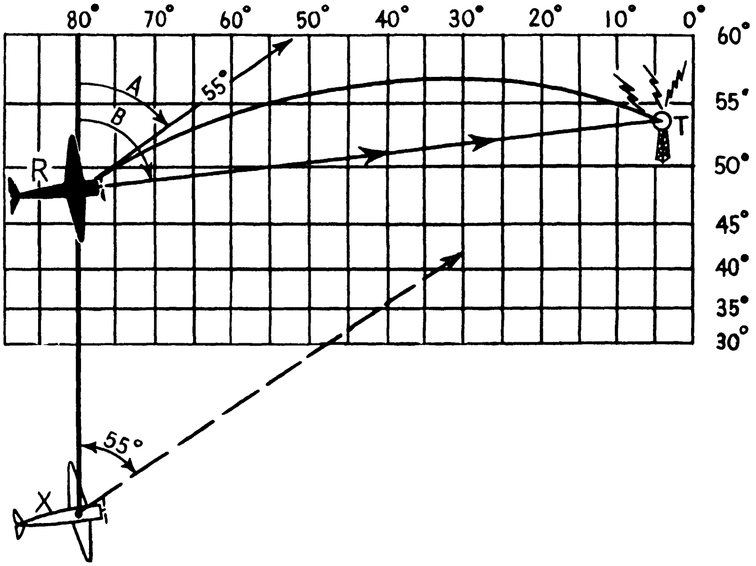


FIG. 192.—The path followed by a radio signal.

the aid of the direction finder were plotted, it would show the plane to be far from position R; it would show the plane to be at X.

In order to utilize radio bearings for line-of-position work on a Mercator chart it is first necessary to make allowance for the difference between the received bearing A and the correct Mercator bearing B. The difference between such bearings may be calculated from the formula

$$\text{Correction} = \frac{\text{difference longitude} \times \sin \text{mid-latitude}}{2}.$$

Tables, however, have been prepared similar to that shown in Table II, which set forth the correction to apply to the received angle A for every practical difference of longitude and mid-latitude between receiver and transmitter. Such tables are normally available to the navigator in flight and should be used as a means of avoiding unnecessary computation.

TABLE II.—RADIO BEARING CORRECTION TABLE

Mid-lat.	Difference of longitude						
	0	2	4	6	8	10	12
0	0	0	0	0	0	0	0
10	0	0.1	0.4	0.5	0.7	0.9	1.0
20	0	0.2	0.7	1.0	1.4	1.7	2.0
30	0	0.5	1.0	1.5	2.0	2.5	2.9
40	0	0.6	1.3	1.9	2.6	3.2	3.8
50	0	0.8	1.5	2.3	3.1	3.8	4.5
60	0	0.9	1.7	2.6	3.5	4.3	5.0
70	0	0.9	1.9	2.8	3.8	4.7	5.6

The bearing correction is always applied to the true bearing obtained with the direction finder. Regardless of the location of the receiver with

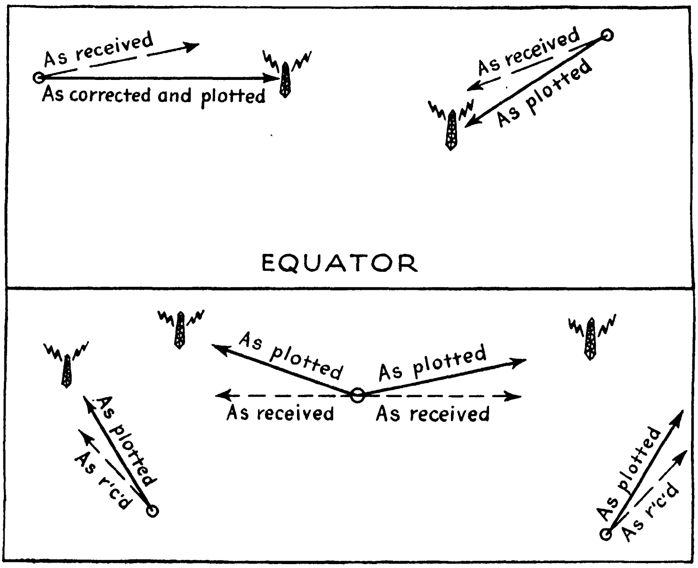


FIG. 193.—Method of correcting radio bearings.

respect to latitude or the transmitter, the correction is always applied in such a manner that the corrected bearing points a little farther toward the equator.

Several pairs of received and plotted bearings are shown in Fig. 193 for the purpose of clarifying this point.

The rule holds good regardless of who takes bearings on whom. If a shore station is requested to take a bearing on the plane's transmission, a report may be received that the plane bears 50° from the shore receiver.

If the tabulated correction is 3°, it must be so applied that the 50° bearing points more toward the equator. In north latitude the corrected bearing—ready for plotting—would therefore be 53°; in south latitude it would be 47°.

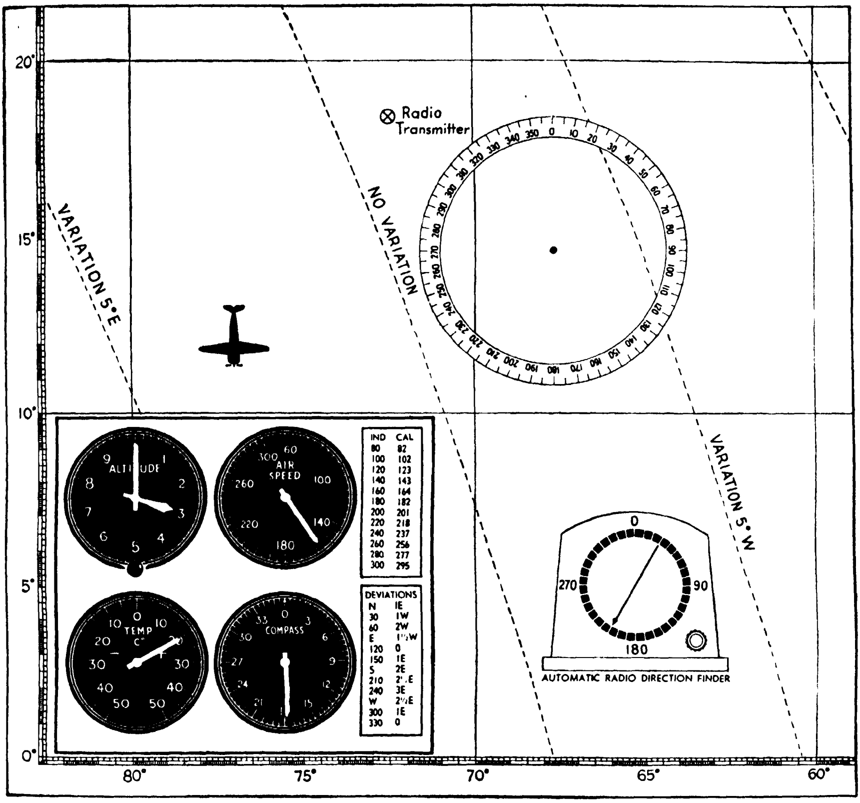


FIG. 194.—Problem 2.

PROBLEMS

1. From the following data determine the true Mercator bearing of the transmitter:

Relative D.F. bearing = 185
True heading = 71

Procedure: 185
71
256 great-circle bearing
4 corr.
252° true Mercator bearing to be plotted

Transmitter position = 50°N. 70°W.
Plane's approx. position = 52°N. 60°W.
Mid-lat. = 51°N.
Diff. long. = 10°
Corr. = 3.8°

2. From the data furnished in Fig. 194 determine what Mercator bearing should be plotted.

3. Determine the Mercator bearing of the transmitter.

Relative bearing = 345	Diff. long. = 12°
Compass heading = 32	Mid-lat. = 35°S.
	Compass error = 14°W

4. Determine the Mercator bearing of the transmitter.

Relative bearing = 136	Diff. long. = 6°
Compass heading = 200	Mid-lat. = 55°N.
	Compass error = 16°E.

5. Determine the Mercator bearing of the transmitter.

Relative bearing = 199	Var. = 20°W.
Compass heading = 199	Dev. = 2°E.
	Diff. long. = 2°
	Mid-lat. = 60°N.

6. Determine the Mercator bearing of the transmitter.

Relative bearing = 313	Var. = 11°E.
Magnetic heading = 002	Diff. long. = 7°
	Mid-lat. = 40°S.

7. Determine the Mercator bearing of the transmitter.

Relative bearing = 090	Var. = 20°W.
Magnetic heading = 040	Mid-lat. = 0°
	Diff. long. = 10°

8. Determine the Mercator bearing of the transmitter.

Relative bearing = 166	Mid-lat. = 50°N
True heading = 51	Diff. long. = 0°

9. From the information contained in Figs. 195 to 200 and Table II, determine what Mercator bearing should be plotted.

10. From the information contained in Figs. 201 to 206,[1] determine the wind between fixes.

11. From information contained in the Figs. 207 to 212,[1] determine the compass heading to point *X*. In these problems assume that the average wind between fixes will continue to act on the plane.

[1] Figures 201 to 212 are contained in the pocket in the back of the book.

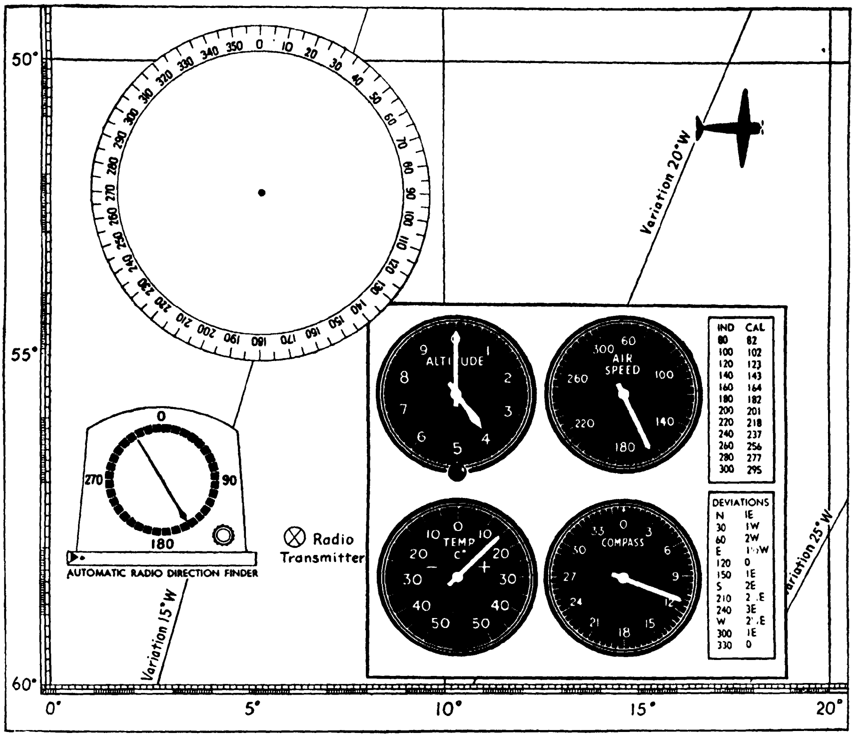


FIG. 195.—Problem 9.

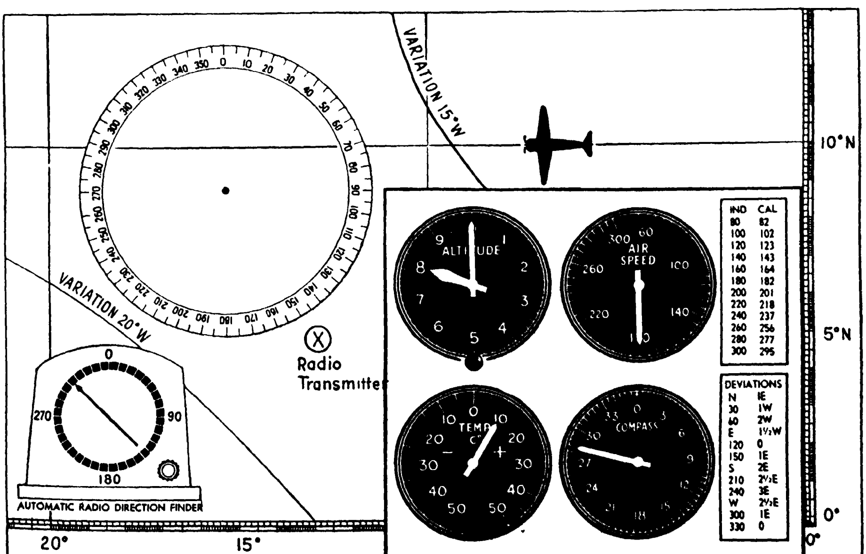


FIG. 196.—Problem 9.

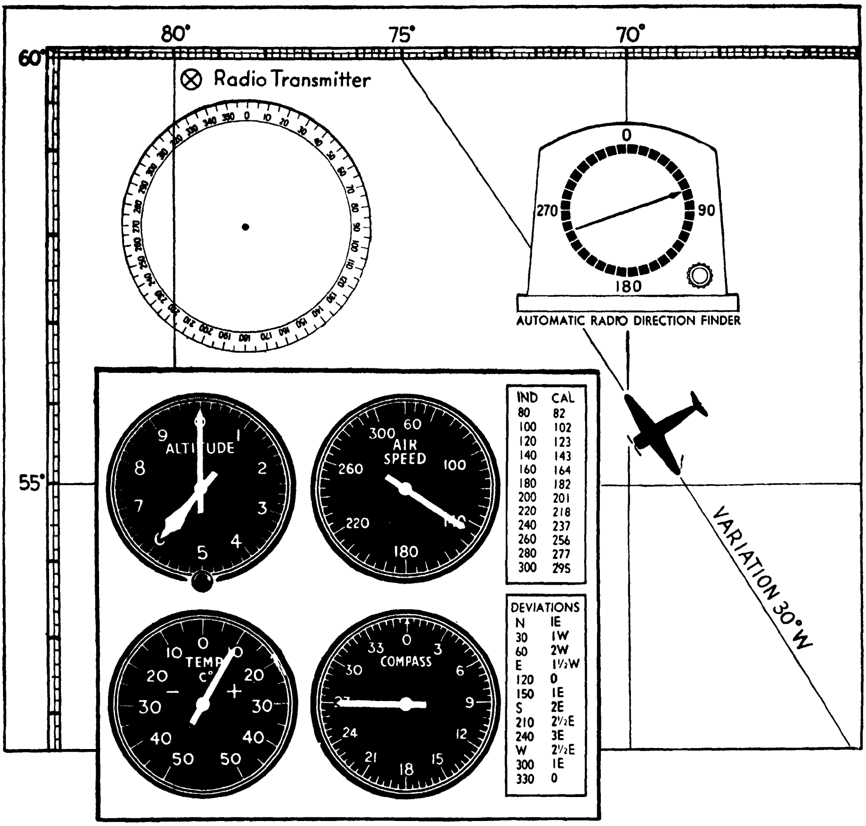


FIG. 197.—Problem 9.

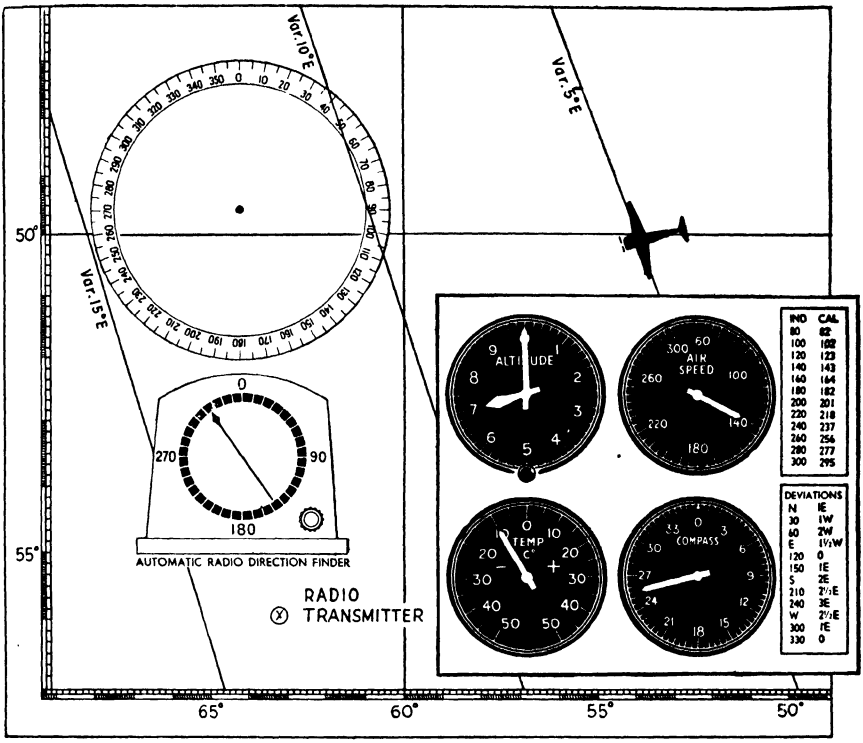


FIG. 198.—Problem 9.

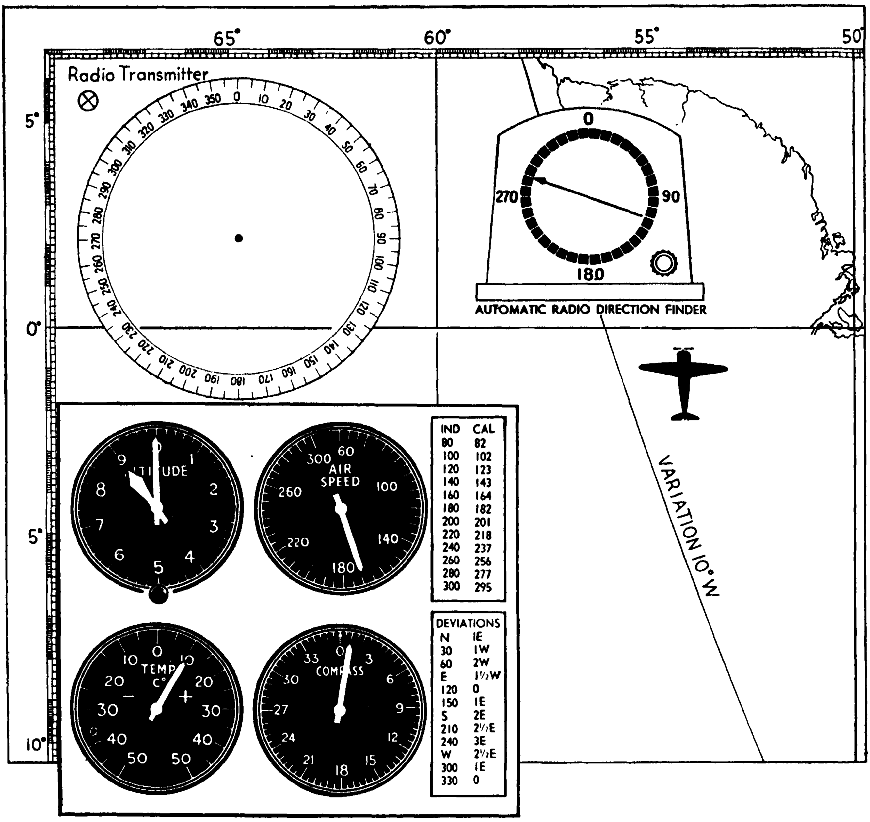


Fig. 199.—Problem 9.

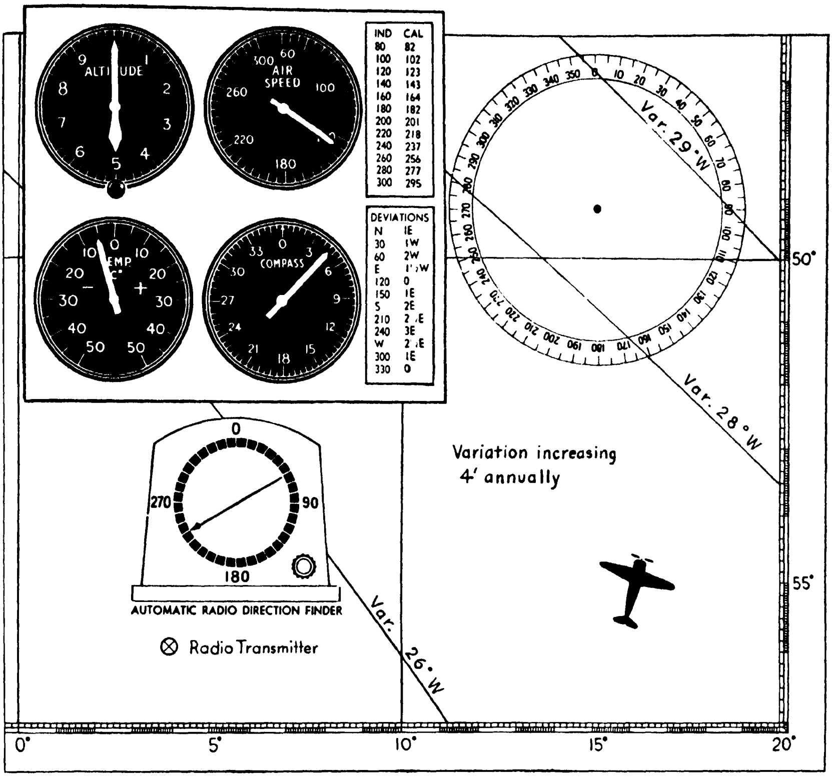


FIG. 200.—Problem 9.

CHAPTER VII

RADIUS OF ACTION AND INTERCEPTION

In Chap. III radius of action was discussed to a limited extent, chiefly to develop the radius-of-action formula used in the ocean navigator's flight plan. Radius of action in general covers a multitude of problems, such as radius of action from a fixed base (see page 63), radius of action from a moving base, and radius of action with respect to alternate bases, area search, etc.

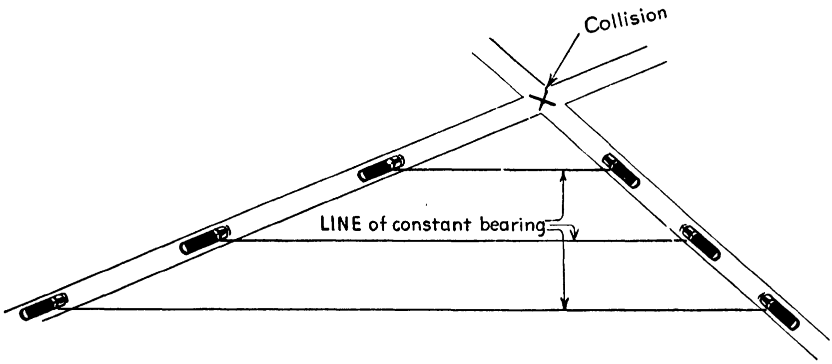


FIG. 213.—Principle of interception.

It is not our purpose to deal with every possible phase of this subject. We shall, however, discuss radius of action with respect to alternate bases; and since this is best approached through a preliminary study of radius of action from a moving base, we shall deal incidentally with this problem. It is also advisable for the ocean navigator to be able to intercept a ship at sea; in military air navigation such interception problems are part and parcel of the navigator's day-to-day routine.

Simple Interception.—An interception problem may always be reduced to a problem of maintaining a constant line of bearing with the objective. If two automobiles or ships meet (intercept), it is because their speeds and tracks are such that the line of bearing between them fails to change; neither is able to draw ahead of the other, and they collide at the intersection of their tracks. This basic principle underlying all interception problems is shown graphically in Fig. 213.

If a navigator desires to intercept a ship, he must head the plane in such a direction that the initial line of bearing (sometimes called the

collision bearing) remains constant throughout the problem. In Fig. 214 a ship at B is shown moving north at a rate of speed that will put it at D at the end of 1 hr. The initial bearing between the plane A and ship is 90°. The line CD is this same 90° bearing redrawn through the position of the ship 1 hr. later at D. The navigator must head the plane in such

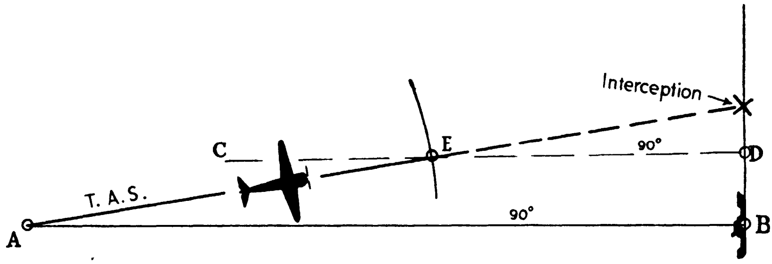


Fig. 214.—Simple interception, no wind.

a direction that it will be somewhere on this line of constant bearing at the end of the hour if ultimate interception is to be achieved.

If there is no wind, this requirement may be met by swinging an arc equal to the plane's true air speed from point A so as to cross the line CD (see Fig. 214). Since there is no wind, the line AE thus established becomes both the true heading and the track. The plane will intercept the ship at the intersection of the two tracks.

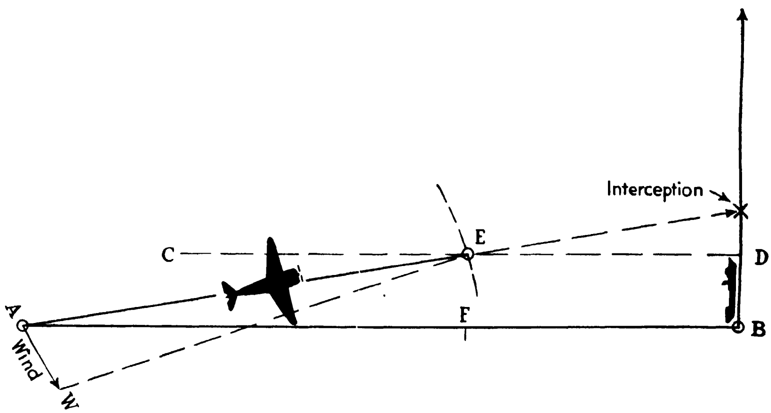


Fig. 215.—Allowance for wind in interception problem.

The method of allowing for wind is shown in Fig. 215. The wind arrow has been drawn from point A, and the true air speed arc has been swung from W so as to intersect the line of bearing CD. Under wind conditions the true heading naturally differs from the track, but the plane will still be located on the line CD at the end of the hour. The inter-

section of the tracks *AE* and *BD* (extended) shows where interception will take place.

Rate of Interception.—It should be noticed in Fig. 215 that the distance *AB* separated plane and ship at the *beginning* of the hour and that the distance *ED* separated them at the *end* of the hour. The difference between these two distances (see the line *AF*) is the hourly **rate of interception.** The rate of interception is invariably measured along the line of constant bearing just as air speed is always measured along the true heading and ground speed along the track.

PROBLEMS

1. The position of a plane and a carrier that it must intercept is shown in Fig. 216. The carrier is proceeding on track 180°, ground speed 20 knots, and the wind

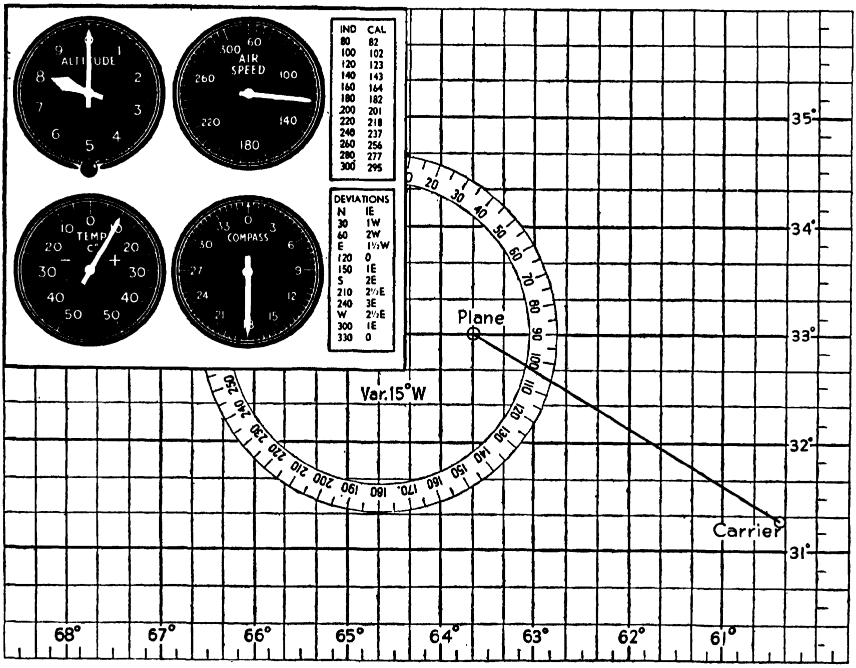


FIG. 216.—Interception problem.

is W20 knots. From the charted information and that shown on the instrument panel (Fig. 216), determine (*a*) the true heading and air speed, (*b*) the track and ground speed, and (*c*) the rate of interception and duration of the interception problem.

Procedure: The only pertinent information available on the instrument panel is that regarding altitude temperature and indicated air speed. From these data the true air speed is found by computer to be 143 knots. The balance of the problem must be solved graphically.

The first step consists in drawing an hour's wind from position P and an hour's movement of the carrier from position C. The carrier's position thus established is labeled X and the end of the wind arrow W. Through point X a dotted line is drawn parallel to PC and becomes the line of constant bearing on which the plane must be located at the end of 1 hr.

The plane's position on this line is determined by swinging an arc equal to the air speed from W so as to cross the line of constant bearing. This is the manner in which point E in Fig. 217 is established, and the line WE becomes the plane's true heading. The plane commenced the interception problem at P and arrived at E at the end of the hour; the line PE indicates the plane's track.

The distance separating plane and carrier at the beginning of the hour is shown by the line PC, and the distance separating them at the end of the hour

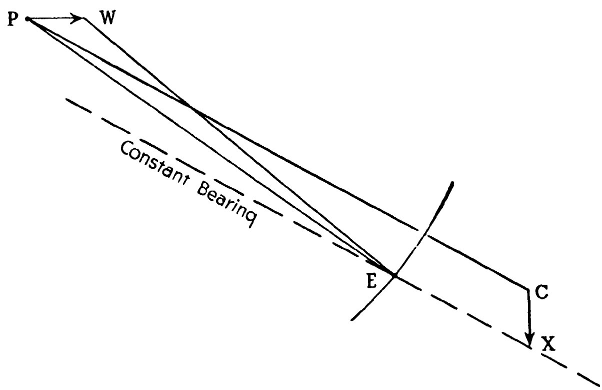


FIG. 217.—Graphic solution of problem shown in Fig. 216.

is shown by the line EX. The distance PC less the distance EX is the rate of interception.

The complete flight data are tabulated below:

True air speed	143 m.p.h.
True heading	131°
Rate of interception	147 m.p.h.
Track	125°
Ground speed	158 m.p.h.

Two hundred miles separated the plane and carrier at the beginning of the problem, and the rate of closure was found graphically to be 147; the duration of the interception problem is obtained by dividing 200 by 147. The duration in this instance is 1 hr. 22 min.

2. The position of a plane and a carrier it must intercept is shown in Fig. 218.[1] The carrier is moving south at the rate of 20 knots. The wind is 240°, 50 knots. With this information and that shown on the instrument panel, determine (*a*) the true heading and air speed, (*b*) the track and ground speed, and (*c*) the rate of interception and duration of the interception problem.

[1] Figures 218 to 221 are contained in the pocket in the back of the book.

3. The position of a plane and a carrier that it is to intercept is shown in Fig. 219.[1] The carrier is moving 140°, 30 knots. The wind is north 50 knots. With this information and that shown on the instrument panel, determine (*a*) the true heading and air speed, (*b*) the track and ground speed, and (*c*) the rate of interception and duration of the interception problem.

4. The position of a plane and a carrier it must intercept is shown in Fig. 220.[1] The carrier is proceeding on track 270° at a ground speed of 20 knots. The wind is west 30 knots. From this information and that shown on the instrument panel, determine (*a*) the true heading and air speed, (*b*) the track and ground speed, and (*c*) the rate of interception and duration of the interception problem.

NOTE: In the event the objective is less than an hour's flight distance from the plane, a slight modification of the graphical analysis becomes necessary. The constant-bearing line is extended through the carrier's position at the end of the first hour. The balance of the problem is performed exactly as previously shown except that the rate of interception is found by adding the distance *DE* (see Figs. 214 and 215) to that originally separating the plane and the carrier.

5. The position of a squadron of planes and a formation of bombers that it is to intercept is shown in Fig. 221.[1] The average wind is west 40 m.p.h. The bombers are proceeding on track 240°, ground speed 275 m.p.h. The true air speed of the interceptors is 300 m.p.h.

Required: The anticipated duration of the interception problem.

Rate of Departure from a Moving Base.—If a plane is ordered to leave a carrier on a mission, its navigator will be supplied with data regarding the track, wind, and the cruising air speed. The problem of following the specified track is the simple triangle-of-velocity problem already familiar to the student. In Fig. 222 a plane has been ordered to scout on track *CR*, and the triangle of velocity *CWP* was constructed in order to determine the true heading out and the ground speed along the track. According to this triangle the plane will arrive at *P* at the end of the first hour.

The pilot or navigator is also supplied with information as to the track and ground speed the carrier will make after his departure. With this information it is possible to predetermine the carrier's position at the end of the first, second, third, or any other number of hours. In Fig. 223, the carrier is shown proceeding on track *CF*, and the ground speed of the carrier is such that the navigator expects it to be at *D*, *E*, and *F* at the end of the first, second, and third hours, respectively. Since the carrier will be at *D* and the plane at *P* at the end of the first hour, the line *DP* represents the hourly rate of departure from the carrier. At the end of the second hour, when the plane is at *Q*, the carrier will be at *E*, and the line *EQ* shows the distance separating the two. This line *EQ* is equal to twice the line *DP* because the plane is now 2 hr. out from

[1] Figures 218 to 221 are contained in the pocket in the back of the book.

the carrier and therefore twice the hourly rate of departure from it. Either the line DP or the line EQ may be considered the line of constant

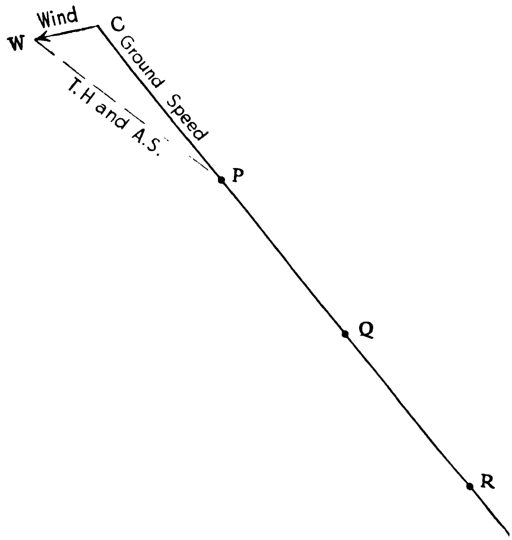


FIG. 222.—Determination of ground speed on a scouting track.

bearing between the plane and carrier; and as long as the respective tracks and ground speeds are maintained, this line of bearing will remain

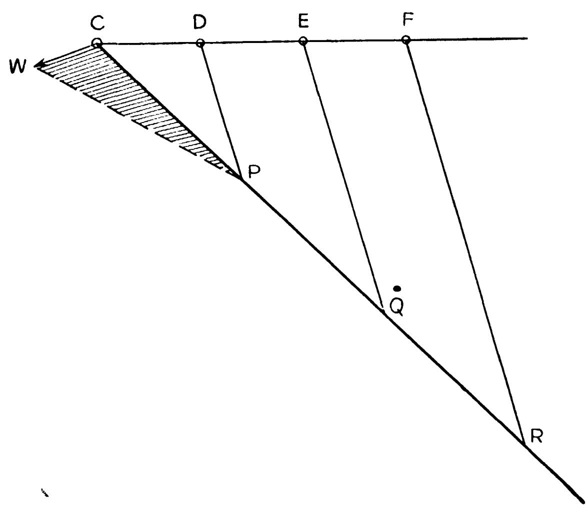


FIG. 223.—Determining rate of departure from a moving base.

constant. If, at any time, the pilot elects to turn back to intercept the carrier, he must head the plane in such a direction that this line of

bearing is kept constant. Failure to do so on the return means that interception will not take place.

Rate of Return to a Moving Base.—If the pilot elects to turn back at the end of the second or third hour, he may construct the simple interception triangle of velocities already discussed. These triangles, shown at the lower right in Fig. 224, are identical because the problem is identical. The problem in either case is to head the plane in such a direction that, if interception is not achieved within the hour, the plane will at least find itself on the line of constant bearing joining the carrier.

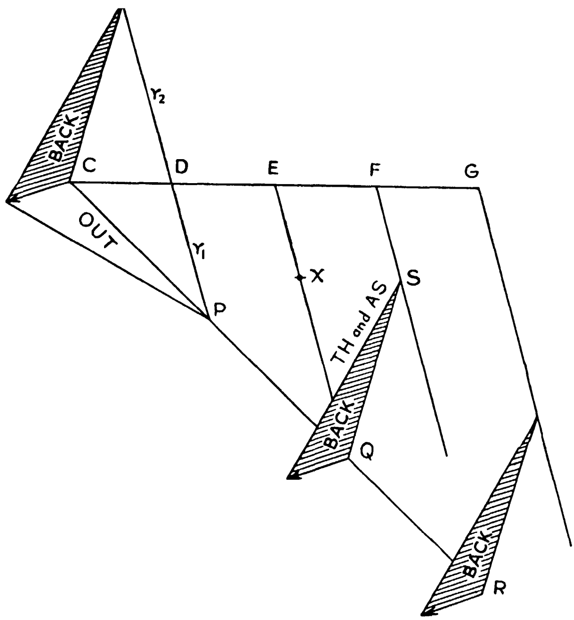


FIG. 224.—Determining rate of return to a moving base.

The rate of interception (*i.e.*, the rate at which the plane approaches the carrier) may be found as follows: Subtract the distance separating them 1 hr. after the plane turns back from the distance that separated them at the *time* of turning back. In Fig. 224, the rate of interception is found by subtracting the line *FS* from the line *EQ*. When this has been done graphically, the line *QX* becomes equal to the rate of return to the carrier. This line *QX* may be compared with the line r_2 in the upper left portion of the figure; the lines are identical in both direction and length.

Radius of Action—Moving Base.—In practice, the return triangle of velocities is constructed, not in flight, but at the same time as the triangle of velocities for the outbound flight. Thus, before the plane leaves the carrier, all the pertinent data regarding headings, tracks, and, most

important of all, the rate out and the rate back become known in advance. Indeed, it is of the utmost importance that these rates be determined in advance for only by means of these can the pilot calculate just how long he can proceed on his mission and still get back to the carrier without running short of fuel. The formula previously used in radius of action from a fixed base is used in determining the allowable flight time out. In the previous problems that involved the use of this formula

$$t_1 = \frac{Tr_2}{r_1 + r_2}$$

the rates out and back were also the ground speeds, and the track along which these were measured was also the line of constant bearing. It must be borne clearly in mind that unless the track is also the line of constant bearing the rates will not necessarily be the same as the ground speeds. In the use to which this formula is now to be put, the rates r_1 and r_2 alone are to be used—never the ground speeds.

If, for example, the rate out is 100 m.p.h. and the rate back 150 m.p.h. and the plane can safely remain in the air a total of 5 hr., the time out to the point of turning is found as follows:

$$\text{Time} = \frac{5 \times 150}{100 + 150} = 3 \text{ hr.}$$

If the distance out along the scouting track is required, it must be obtained by multiplying the allowable time out by the ground speed out.

PROBLEMS

1. A plane is ordered to take off from a carrier and scout on track 140°. The following flight data are available:

Carrier's track and ground speed	090°	30 knots
Wind direction and velocity	60°	40 knots
Plane's true air speed		120 knots
Total fuel capacity	6 hr.	
Reserve requirement	1 hr.	

Required: Determine the following:
True heading out.
True heading back.
Track and ground speed out.
Track and ground speed back.
Rate of departure from the carrier.
Rate of return to the carrier.
Time out to the point of turning back.

Procedure: The graphical solution of this problem is shown in Fig. 225. By scaling the sides and angles, the following pertinent flight data become known:

True heading out	121°	
True heading back	008°	
Track and ground speed out	140°	106 knots
Track and ground speed back	352°	98 knots
Rate of departure from carrier		90 knots
Rate of return to carrier		106 knots

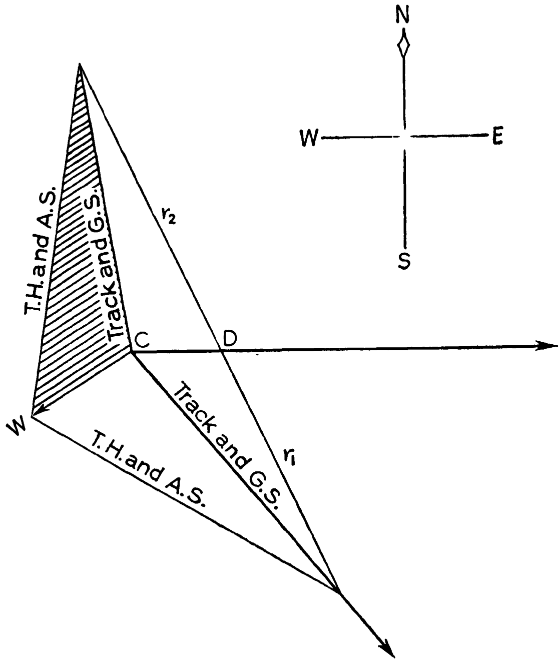


FIG. 225.—Graphic solution of radius-of-action problem from a moving base.

The time out to the point of turning back to intercept the carrier is determined by use of the formula

$$\text{Time} = \frac{5 \times 106}{90 + 106} = 2.7 \text{ hr.}$$

2. The position of a plane and carrier, together with the carrier's track and the plane's scouting track, is shown in Fig. 226.[1] A 5-hr. fuel supply is carried by the plane, including an hour's reserve. The following data are available:

Carrier's ground speed	20 knots
Wind	350°, 30 knots
Plane's cruising air speed	120 knots

Required: (*a*) When must the plane turn back to intercept the carrier? (*b*) How far will it have proceeded along its scouting track?

3. The position of a plane and carrier, together with the carrier's track and the plane's scouting track, is shown in Fig. 227.[1] A 4-hr. fuel supply is carried by the plane, including a 30-min. reserve. The following data are available:

[1] Figures 226 and 227 are contained in the pocket in the back of the book.

Carrier's ground speed	20 knots
Wind	200°, 20 knots
Plane's cruising air speed	140 knots

Required: (*a*) When must the plane turn back to intercept the carrier? (*b*) How far will it have proceeded along its scouting track?

Radius of Action—Alternate Base.—In this type of problem the navigator is concerned as to how long he may proceed toward his destination and still get to an alternate airport if circumstances make this necessary. The problem is solved in exactly the same manner as the problem concerning radius of action from a moving base. When a pilot

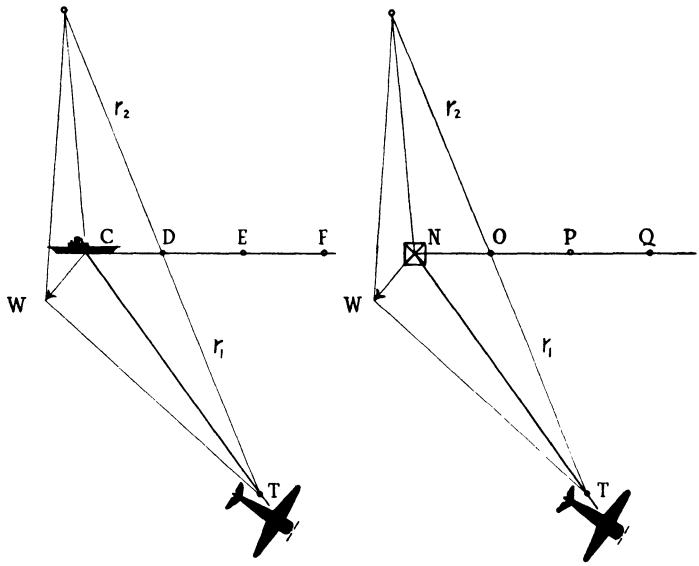


FIG. 228.—Radius of action—moving base compared with alternate base.

takes off from a moving base, such as a carrier, subsequent maneuvering on the part of the ship is of academic importance to him as long as he knows where this ship will be when he has used up his available fuel. Similarly, in the case of alternate-airport problems, the pilot does know in advance where he may land at the expiration of his allowable flight time.

Both problems are shown in Fig. 228 for comparison; that at the left is the carrier-base problem, and that at the right is the alternate-base problem. In each case the planes flew out along identical tracks *CT* and *NT* with 3 hr. usable fuel supply. In the carrier problem, the ship moved from *C* to *F* in 3 hr. and was at *D* (one-third this distance) at the end of 1 hr. The method of determining the allowable flight time along track *CT* has just been discussed.

In the alternate-base problem, the navigator *assumed* that he took off from a moving base which would be at Q in 3 hr. and which would therefore be at O at the end of 1 hr. Q is actually the alternate airport, and N, of course, is the airport from which the plane departed.

Prior to departure, each navigator drew identical graphic analyses and using the rates thus obtained calculated how long the planes could proceed along their tracks before turning to get back to the carrier in the one instance and the alternate airport in the other.

The first of the following problems will be worked out as if the plane had not yet taken off from its airport and the pilot wished to know in advance how far he might proceed toward his destination and still get to his alternate airport without using his reserve. The problem becomes of special interest, however, to a navigator approaching his terminal after a long ocean flight, if information is received that the terminal weather may not permit landing.

PROBLEMS

1. In the accompanying chart (Fig. 229) the position of the plane (A) and the position of the alternate base are shown, together with the track from the plane's position to its destination. The destination is not shown on the chart, for it does not enter into the working of the problem. It was taken into consideration in determining the plane's fuel load and track. The following information is assumed to be available:

Wind	270°, 20 knots
True air speed	120 knots
Total fuel supply	6 hr.
Reserve requirement	1 hr.

Procedure: a. Draw the track line from the plane's position A to the alternate base, and scale the distance. In this instance the distance is 300 miles.

b. Divide this distance by the allowable flight hours (300 divided by 5), and spot in a point X 60 miles distant from A toward the alternate base.

c. Draw the wind arrow AW from A.

d. Using the true air speed as a radius, swing a semicircular arc from point W; this arc cuts the destination track line at P.

e. Draw a straight line from P through X to the other side of the semicircle; label this latter point Y.

f. Draw the following lines: AY, WY, and WP. This completes the graphic construction.

The distance PX and the distance XY must be measured, for PX is r_1 and XY is r_2 in the radius-of-action formula. The allowable flight time along the destination track is found as follows:

$$\text{Time} = \frac{5 \times 140}{86 + 140} = 3.1 \text{ hr., or 3 hr. 6 min.}$$

In point of fact, as far as this problem is concerned, the graphic analysis could have been completed without drawing the lines AY, WY, and WP as these lines represent the track to the alternate, the true heading to the alternate, and the true heading to the original destination, respectively. Since this problem was worked on the assumption that the plane had not yet left the field for its destination, these values were conveniently determined in advance.

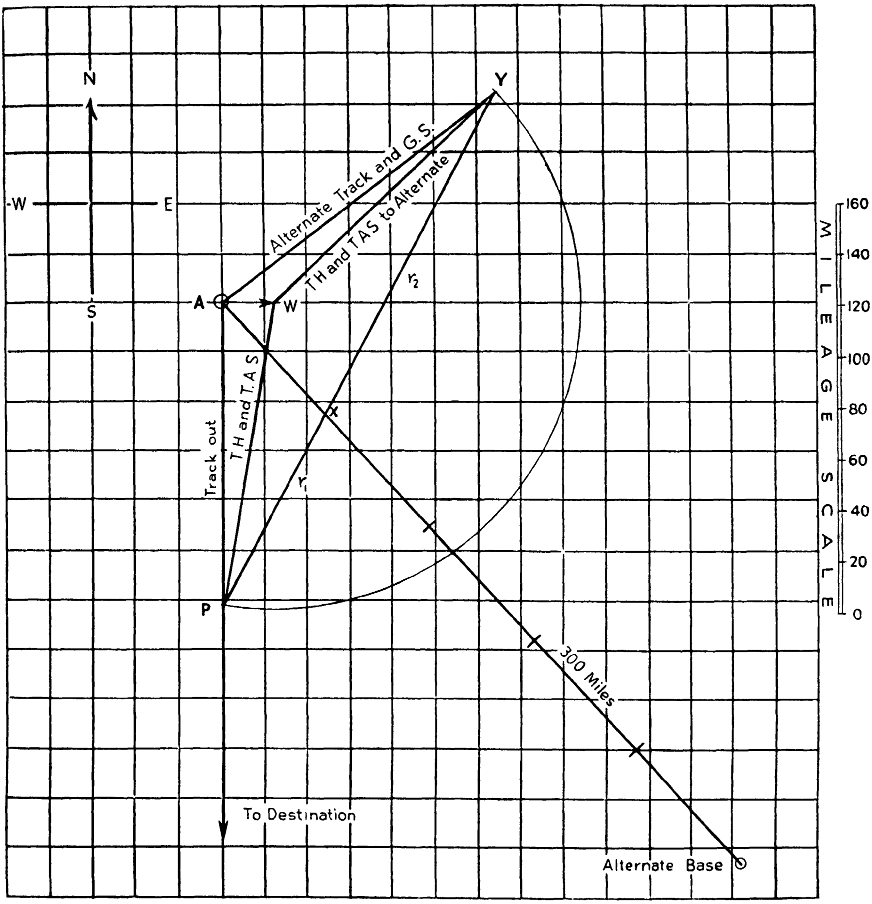


FIG. 229.—Alternate base, Prob. 1.

The complete flight data are tabulated below:

True heading out	190°
Track out	180°
Ground speed out	118 knots
True heading to alternate (after turning)	49°
Track to alternate (after turning)	55°
Ground speed to alternate (after turning)	137 knots
r_1	86 knots
r_2	140 knots

2. The position of a plane, its instrument panel, and its alternate base are shown in Fig. 230.[1] The drift is 15° left, the surface wind direction is 250°, and a 4-hr. fuel supply is available.

Required: How far can the plane proceed along its present track and still reach the alternate base without using the reserve gas?

3. The position of a plane, its instrument panel, and its alternate base are shown in Fig. 231.[1] The surface wind direction is 40° true, and the drift is 10° right. A 3-hr. fuel supply (exclusive of reserve) is available.

Required: How far can the plane proceed along its present track and still reach the alternate base without using the reserve gas?

4. The position of a plane, its track, and its alternate base are shown in Fig. 232.[1] The true air speed of the plane is 150 knots; the wind is 30°, 25 knots. A 3-hr. fuel supply is available.

Required: How far can the plane proceed on this track and still reach the alternate base without using the reserve gas?

5. The position of a plane, its instrument panel, and its alternate base are shown in Fig. 233.[1] The drift is shown. The timed passage of whitecaps between 30° speed lines averages 15.2 sec. A 4-hr. fuel supply is available.

Required: How far can the plane proceed along its present track and still reach its alternate base without using the reserve gas?

[1] Figures 230 to 233 are contained in the pocket in the back of the book.

CHAPTER VIII

PRINCIPLES OF CELESTIAL NAVIGATION

Celestial navigation deals with lines of position obtained through observations of the sun, moon, stars, and planets. It is not a substitute for either radio navigation or dead reckoning;[1] each supplements the other; each adds something to the navigator's information regarding the position of his plane. It is possible by means of radio to orient a plane and locate it very accurately above a transmitting station. It is not yet practical to locate an objective with absolute precision entirely by means of celestial navigation. When working under favorable flight conditions, an experienced air navigator is able to fix his plane's position within 5 miles by the use of heavenly bodies. Approximately 15 min., however, is required to do this, and during this interval the plane may move 30 to 60 miles. Consequently, the navigator is continually dealing with historical information when he uses celestial navigation alone; he finds out where he *was* by means of celestial observation, but he knows where he *is* only by carrying forward his position by means of dead reckoning.

Celestial navigation is particularly applicable to ocean flying where landmarks and radio aids are scarce. This method of navigation has one distinct merit: a celestial fix may be in error 5 miles, but this error is nonaccumulative; it remains constant whether the plane is 100 or 2,000 miles from its base. The same cannot be said of either dead reckoning or radio navigation; the farther a plane proceeds from its base or radio station, the more uncertain its position becomes. The student's attention is again called to the use of tolerances.

Theory of Circles of Equal Altitude.—The classic "flagpole" analogy is reviewed here briefly in order to outline the principle underlying the use of heavenly bodies for lines of position.

If several observers are stationed around a flagpole in a circle as shown in *A*, Fig. 234, each observes the same elevation or altitude of the top of the pole. The circle on which these observers are stationed may properly be termed a **circle of equal altitude.** If the observers were to move closer to the flagpole, each would observe a greater altitude. If they were to move away from the flagpole, each would observe a lesser altitude. In other words, their distance from the base of the flagpole is dependent on the observed altitude of its top, and vice versa.

[1] Navigation by methods other than radio, celestial, or landmarks.

In a similar manner a navigator determines his distance from a point on the earth directly underneath a celestial body by observing the elevation (altitude) of this body above his horizon. Reference to *B*, Fig. 234, shows that the same altitude of a given star can be observed by two different navigators at the same time and, when this happens, both are equidistant from the point on the earth directly underneath that star.

Such a circle of equal altitude is shown in *C*, Fig. 234, as it might be drawn on a Mercator chart. The exact center of this circle (*X*) is directly

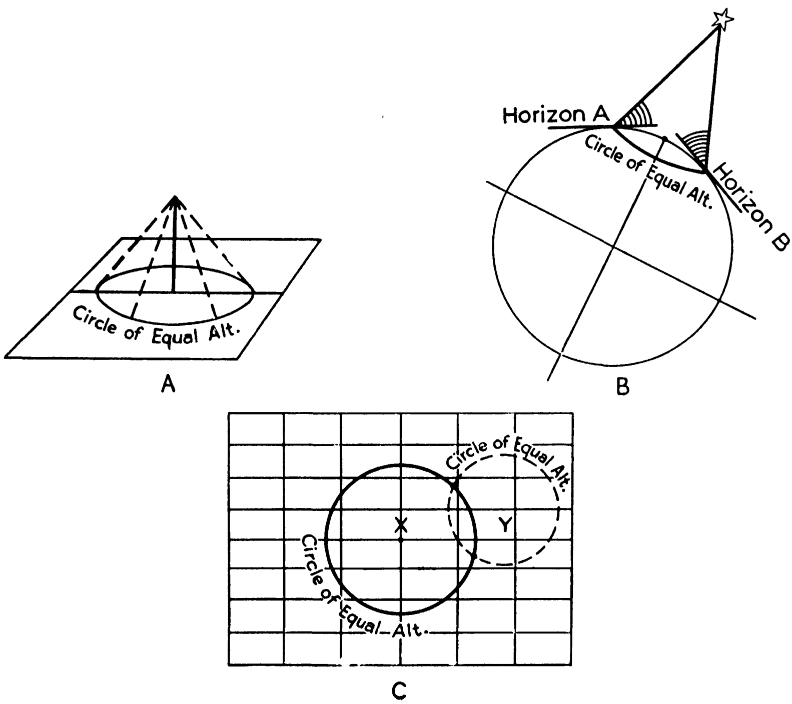


FIG. 234.—Theory of circle of equal altitude.

underneath the star; any observer at any point on this circle must obtain, simultaneously, the same altitude as any other observer.

It should be apparent that establishment of the plane's position on this circle is not in itself enough to locate the plane's position except within wide limits; but if it becomes possible to establish a second circle of equal altitude (*Y*), these two circles may intersect as shown in *C*. Since the plane is known to be situated on each circle, it can be in only one of two places. Usually these two possible positions are so far apart that only one of them may be logically considered the correct position of the plane.

In order to acquire a working knowledge of the use of circles of equal altitude, prior study of the earth and its relationship to the celestial sphere becomes necessary.

Earth and the Celestial Sphere.—The celestial sphere is a globe of astronomical proportions concentric with the earth, and it is on this enormous sphere that the sun, moon, stars, and planets are seen. It should be pointed out that celestial bodies are actually at different distances from the earth but these distances are so great that, to the eye, all appear equidistant from the earth.

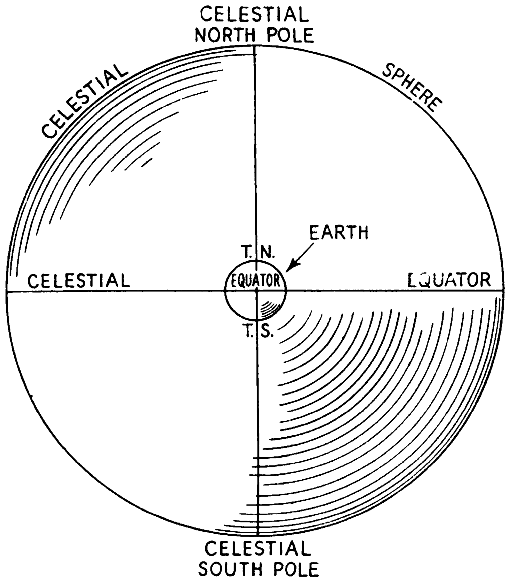


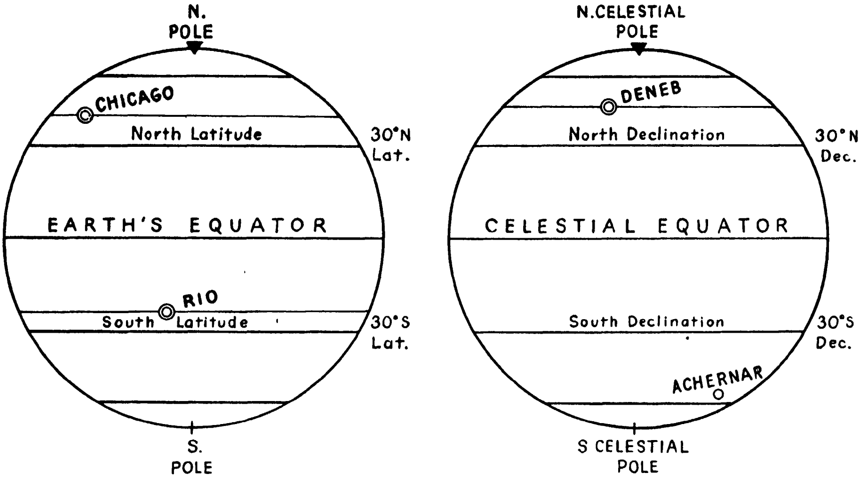
FIG. 235.—The earth and the celestial sphere.

The celestial sphere has true north and south poles, which are extensions of the earth's true north and south poles. It also has a celestial equator formed by extending the plane of the earth's equator. This relationship between the earth and celestial sphere is shown in Fig. 235.

Position of Stars—Declination.—For all practical purposes the stars may be considered *fixed* pin points of light on the celestial sphere. Even the closest star is so many million light-years distant that, while it may have motion of its own, this motion is indiscernible to the navigator. Year after year the stars maintain their relative positions within very close limits; they may be located on the celestial sphere just as positively as Chicago, Boston, or Miami may be located on the earth.

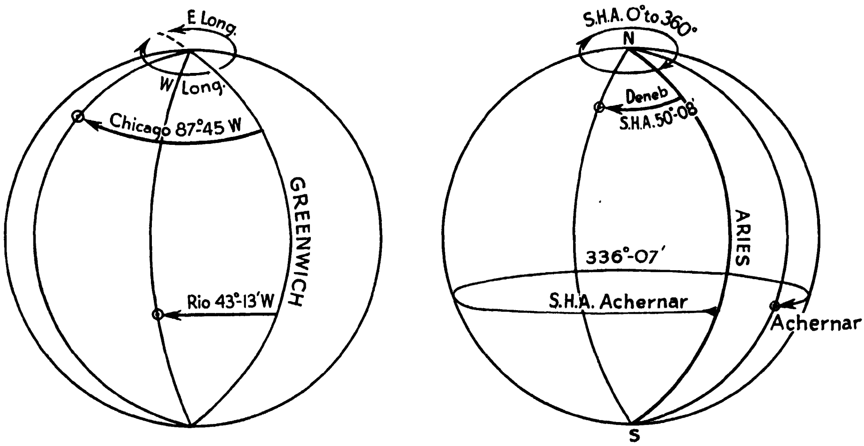
Some of the navigational stars are located north of the celestial equator, and some are located south; the term **declination** is used in place of the term *latitude* to express this location north or south of the

celestial equator. Chicago, for example, is 41°45′ north of the equator and is therefore said to be in latitude 41°45′N. The star Deneb is 45°05′ north of the celestial equator and therefore has a declination of



EARTH (Exaggerated) CELESTIAL SPHERE (Reduced)

FIG. 236.—Comparison between latitude and declination.



THE EARTH THE CELESTIAL SPHERE

FIG. 237.—Comparison of longitude and SHA.

45°05′N. Rio de Janeiro is in latitude 22°54′S.; the star Achernar has a declination of 57°32′S. The relationship between latitude on the earth and declination on the celestial sphere is shown in Fig. 236.

Position of Stars—SHA.—The measurement of declination suffices only to locate a star with respect to the celestial equator. The term

sidereal hour angle (SHA) is used in place of the term *longitude* to locate stars with respect to the celestial zero meridian Aries; sidereal means

STARS

Alphabetical order				Order of SHA			
Name	Mag.	SHA	Dec.	SHA	Dec.	RA	Name
		° ′	° ′	° ′	° ′	h m	
Acamar.	3.4	315 59	S40 32	14 31	N14 54	23 02	Markab
Achernar . . . 1	0.6	336 07	S57 32	16 23	S29 56	22 54	**Fomalhaut**
Acrux 2	1.1	174 08	S62 47	28 51	S47 14	22 05	Al Na'ir
Adhara. . . . †	1.6	255 54	S28 54	34 39	N 9 37	21 41	Enif
Aldebaran . . 3	1.1	291 50	N16 24	50 08	N45 05	20 39	**Deneb**
Alioth	1.7	167 07	N56 16	54 43	S56 55	20 21	Peacock
Al Na'ir	2.2	28 51	S47 14	63 00	N 8 43	19 48	**Altair**
Alnilam. . . . †	1.8	276 40	S 1 14	77 04	S26 22	18 52	Nunki
Alphard . . . †	2.2	218 48	S 8 25	81 15	N38 44	18 35	**Vega**
Alphecca . . . †	2.3	126 56	N26 54	84 54	S34 25	18 20	Kaus Aust
Alpheratz. . . 4	2.2	358 39	N28 47	91 11	N51 30	17 55	Etamin
Al Suhail	2.2	223 31	S43 12	96 56	N12 36	17 32	Rasalague
Altair 5	0.9	63 00	N 8 43	97 34	S37 04	17 30	Shaula
Antares . . . 6	1.2	113 31	S26 18	103 13	S15 39	17 07	Sabik
Arcturus . . . 7	0.2	146 44	N19 29	(109 21)	S68 55	16 43	α Tri Aust
ε Argus.	1.7	234 39	S59 20	113 31	S26 18	16 26	**Antares**
Bellatrix . . . †	1.7	279 29	N 6 18	120 46	S22 28	15 57	Dschubba
Betelgeux . . 8	0.1–1.2	271 59	N 7 24	126 56	N26 54	15 32	Alphecca
Canopus . . . 9	−0.9	264 20	S52 40	(137 17)	N74 23	14 51	Kochab
Capella. . . 10	0.2	281 53	N45 57	141 04	S60 36	14 36	**Rigil Kent.**
Caph	2.4	358 28	N58 50	146 44	N19 29	14 13	**Arcturus**
θ Centauri . . .	2.3	149 10	S36 05	149 10	S36 05	14 03	θ Centauri
β Crucis	1.5	168 54	S59 23	159 27	S10 52	13 22	**Spica**
γ Crucis . . .	1.6	173 00	S56 48	159 35	N55 13	13 22	Mizar
Deneb . . . 11	1.3	50 08	N45 05	167 07	N56 16	12 52	Alioth
Deneb Kait. . †	2.2	349 49	S18 18	168 54	S59 23	12 44	β Crucis
Denebola . . . †	2.2	183 28	N14 53	173 00	S56 48	12 28	γ Crucis
Dschubba . . .	2.5	120 46	S22 28	174 08	S62 47	12 23	**Acrux**
Dubhe . . . 12	2.0	194 56	N62 03	183 28	N14 53	11 46	Denebola
Enif	2.5	34 39	N 9 37	194 56	N62 03	11 00	Dubhe
Etamin.	2.4	91 11	N51 30	208 40	N12 15	10 05	**Regulus**
Fomalhaut . 13	1.3	16 23	S29 56	218 48	S 8 25	9 25	Alphard
Hamal . . . . †	2.2	329 01	N23 12	(221 50)	S69 29	9 13	Miaplacidus
Kaus Aust. . . .	2.0	84 54	S34 25	223 31	S43 12	9 06	Al Suhail
Kochab	2.2	(137 17)	N74 23	234 39	S59 20	8 21	ε Argus
Marfak.	1.9	309 56	N49 40	244 32	N28 10	7 42	**Pollux**
Markab	2.6	14 31	N14 54	245 55	N 5 22	7 36	**Procyon**
Miaplacidus. . .	1.8	(221 50)	S69 29	255 54	S28 54	6 56	Adhara
Mizar	2.4	159 35	N55 13	259 20	S16 38	6 43	**Sirius**
Nunki	2.1	77 04	S26 22	264 20	S52 40	6 23	**Canopus**
Peacock . . 14	2.1	54 43	S56 55	271 59	N 7 24	5 52	**Betelgeux**
Polaris	2.1	(333 57)	N89 00	276 40	S 1 14	5 33	Alnilam
Pollux . . . 15	1.2	244 32	N28 10	279 29	N 6 18	5 22	Bellatrix
Procyon . . 16	0.5	245 55	N 5 22	281 53	N45 57	5 12	**Capella**
Rasalague . . †	2.1	96 56	N12 36	282 03	S 8 16	5 12	**Rigel**
Regulus . . 17	1.3	208 40	N12 15	291 50	N16 24	4 33	**Aldebaran**
Rigel . . . 18	0.3	282 03	S 8 16	309 56	N49 40	3 20	Marfak
Rigil Kent. . 19	0.3	141 04	S60 36	315 59	S40 32	2 56	Acamar
Ruchbah	2.8	339 29	N59 56	329 01	N23 12	2 04	Hamal
Sabik	2.6	103 13	S15 39	(333 57)	N89 00	1 44	**Polaris**
Shaula	1.7	97 34	S37 04	336 07	S57 32	1 36	**Achernar**
Sirius . . . 20	−1.6	259 20	S16 38	339 29	N59 56	1 22	Ruchbah
Spica . . . 21	1.2	159 27	S10 52	349 49	S18 18	0 41	Deneb Kait.
α Tri. Aust.. .	1.9	(109 21)	S68 55	358 28	N58 50	0 06	Caph
Vega. . . . 22	0.1	81 15	N38 44	358 39	N28 47	0 05	Alpheratz

SHA = 360° − RA GHA* = GHA♈ + SHA* Jan.-Apr., 1943

FIG. 238.—Star tabulation from the American Air Almanac.

"pertaining to the stars." There is one important difference between SHA and longitude. Longitude on the earth is measured both to the

east and to the west of the zero Greenwich meridian and never exceeds a value of 180°. SHA is *always measured to the westward* from the meridian of Aries and consequently may attain a value up to 360°.

The longitude of Chicago is 87°45′ west of Greenwich; the SHA of the star Deneb is 50°08′, and the designation *west* is not written, because SHA is always measured to the west. The longitude of Rio de Janeiro is 43°13′ west of Greenwich; the SHA of Achernar is 336°07′. Longitude and SHA are compared in Fig. 237.

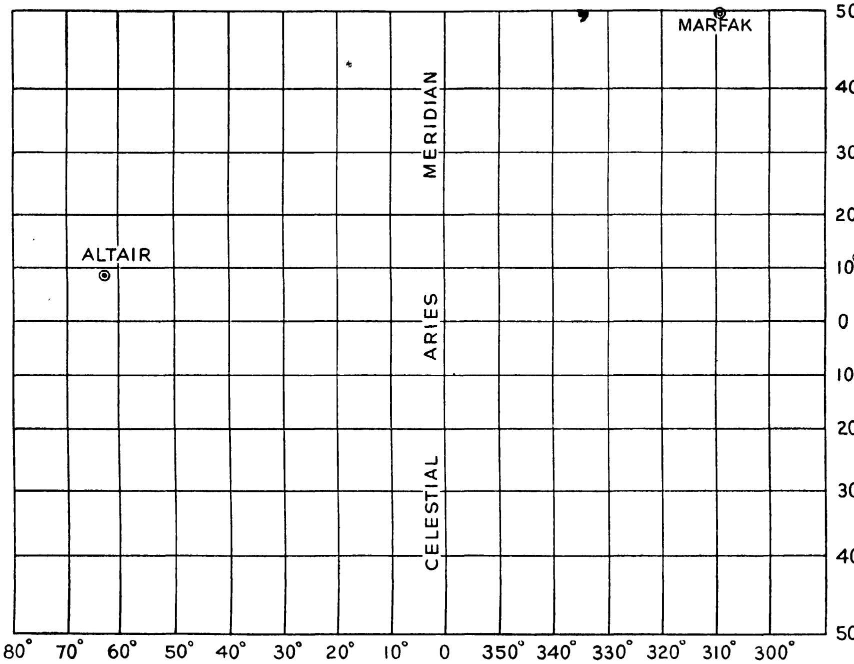


FIG. 239.—Star chart.

Tabulated Position of Stars—American Air Almanac.—The SHA and declination of 55 navigational stars are tabulated on the inside back cover of the American Air Almanac. This tabulation is reproduced in Fig. 238.

Inspection of this tabulation shows that Altair is located on the celestial sphere 8°43′ north of the celestial equator and 63° west of the celestial zero meridian Aries. Marfak is located 49°40′ north of the celestial equator, and its SHA is 309°56′. The position of these two stars is shown on a Mercator projection of the heavens in Fig. 239.

Problem: Locate the following stars on the chart in Fig. 239 by means of SHA and declination.

Acamar.	Deneb.
Nunki.	Alpheratz.
Vega.	Deneb Kaitos.

Star Identification.—The student should become familiar with the 55 navigational stars listed on the inside back cover of the American Air Almanac and should be able to identify each star by means of two separate sets of pointers. It is intended, by means of the pointer system, that a star will be identified by its relation to other navigational stars near by or that it will be positively identified by means of some special formation of stars close to it.

The star Polaris (poe-lay′-ris), commonly called the North Star, is located about 1° from the true north celestial pole. It is most easily located by means of Ursa Major, a dipperlike arrangement of stars shown in Fig. 240. The first two stars in this group point almost directly to Polaris.

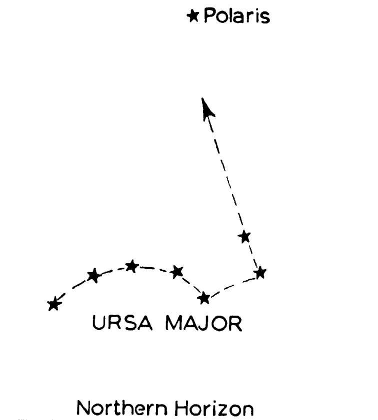


FIG. 240.—Star identification.

When the meridian of Aries is directly over that of the observer, the Big Dipper (Ursa Major) is found underneath Polaris with the handle to the westward. At the same time Cassiopeia, a W-shaped constellation of five stars, is located upside down above Polaris. These two constellations are shown in Fig. 241; the names of the stars and the accepted pronunciation appear below.

Big Dipper		Cassiopeia	
Dubhe	(dub′-ay)	Caph	(calf)
Merak	(me′-rack)	Schedir	(shed′-ear)
Pheeda	(feek′-dah)	Gamma	(gam′-ma)
Megrez	(Meh′-grez)	Ruchbah	(ruck′-bah)
Alioth	(al′-e-ahth)	Epsilon	(ep′-se-lon)
Mizar	(my′-zar)		
Alkaid	(al-kade′)		

These stars are all second-magnitude stars and because of this are seldom used if brighter stars are available. A few of these stars are listed in the American Air Almanac; the chief function of the others is to assist in locating other navigational stars. This latter function is important in northern latitudes where one or the other of these constellations is usually visible. In high northern latitudes both these constella-

tions may be seen to rotate slowly counterclockwise around Polaris. Kochab (ko′-chab) is a second-magnitude star between Polaris and the

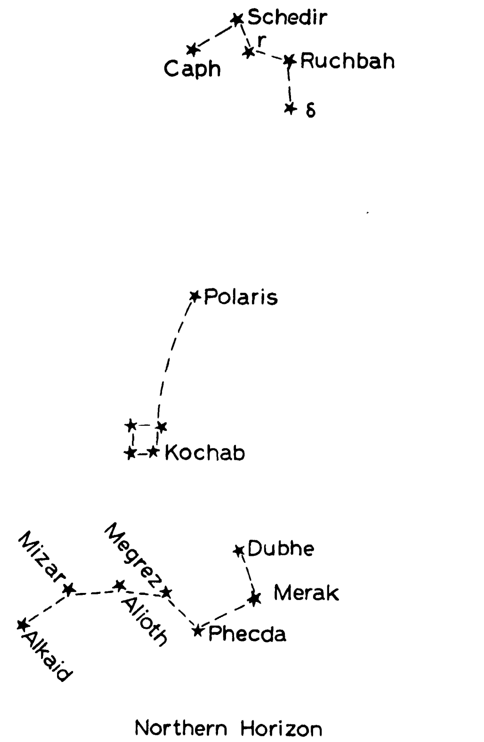


Fig. 241.—Star identification.

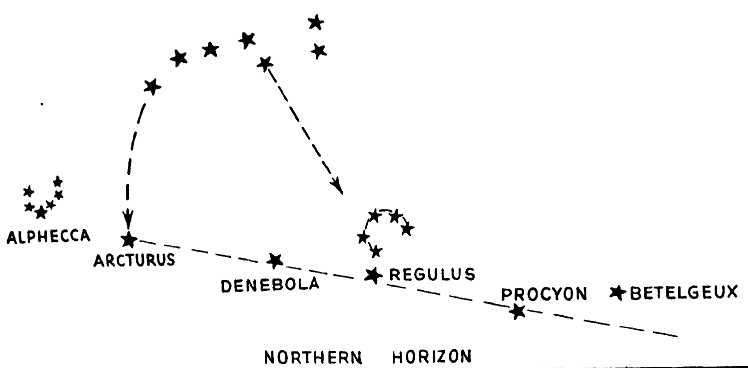


Fig. 242.—Star identification.

Big Dipper; its position is such that it appears about to drop into the Dipper.

Arcturus (ark-too′-rus), a prominent orange-colored star, is located by continuing the curvature of the handle of the Big Dipper through Alkaid for a distance equal to about 1½ times the length of the handle. It should be pointed out that color alone is a poor means of identifying any star since haze conditions alter color characteristics radically.

Above this curve line (see Fig. 242) is a U-shaped group of stars containing Alphecca (al-fec′-ah). This group is known as the Northern Crown. Regulus (reg′-ewe-lus), a bright star located in the handle of a sickle-like formation, is found by drawing a line from Megrez south through Phecda, as shown.

A straight line from Arcturus through Regulus passes through Denebola (de-neb′-oh-lah), which is located approximately midway

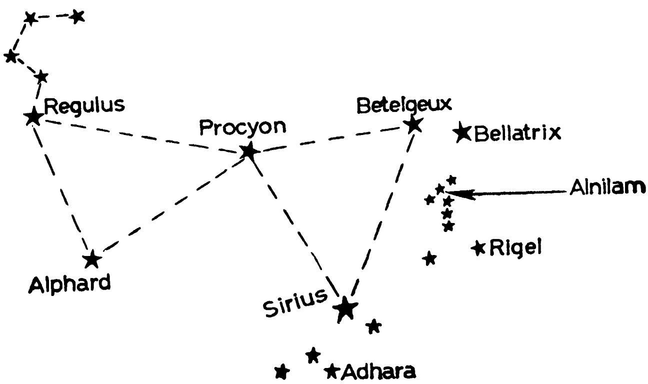


FIG. 243.—Star identification.

between the two; if this line is continued beyond Regulus, it will be found to lead almost directly to Procyon (pro′-see-on) and slightly south of Betelgeux (bet′-el-juz).

Alphard (al-fard′), Regulus, and Procyon form a right-angle triangle with the right angle at Alphard, as shown in Fig. 243. There are no bright stars close to Alphard. Procyon, Betelgeux, and Sirius (seer′-ee-us) to the south form a perfect equilateral triangle. Betelgeux, an orange-colored star, is one of the most prominent stars in the constellation Orion (o-rye′-on); two others, *viz.*, Bellatrix (beh-lay′-trix) and Rigel (rye′-gel), are frequently used for navigational purposes. These are also shown in Fig. 243.

Alnilam (al′-nih-lam) is in the center of a group of three stars known as Orion's Belt. It is used occasionally for navigation purposes, but when so used it is never astigmatized. When astigmatized its identity is confused with the stars on either side. Adhara (ad-ha′-rah) is opposite Sirius in a small quadrangle, as shown in Fig. 243.

Betelgeux, Procyon, and Pollux (pol′-lux) form a right-angle triangle with the right angle at Procyon; Pollux is north of the line between Betelgeux and Procyon. Pollux and Castor (cas′-tor) are relatively close together and are of almost identical brilliance. If one of these stars is to be used, it must be carefully identified. Remembering that Castor is the more northerly of the two is helpful. Aldebaran (al-deb′-ah-ran) is at the corner of a V-shaped formation of faint stars located midway

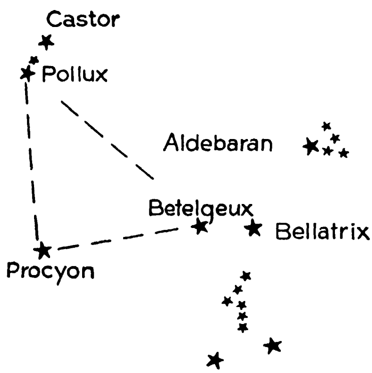


FIG. 244.—Star identification.

between Bellatrix and the Pleiades (plee′-ya-dez). Aldebaran may also be located by drawing a straight line through Orion's Belt up past Bellatrix. The Pleiades are a small cluster of stars located as shown in Fig. 244.

If a straight line is drawn from Phecda out through the next two stars forming part of the handle of the Dipper, it will locate Vega (vee′-

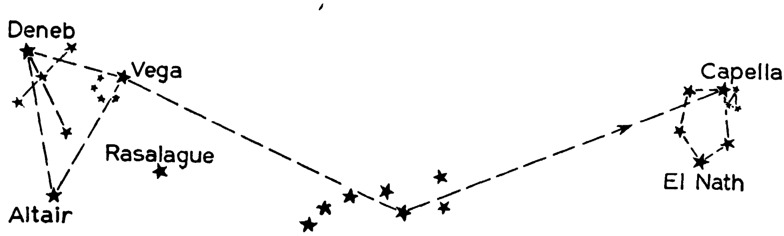


FIG. 245.—Star identification.

gah). Vega may be further identified on a clear night by means of two pairs of "pigeon-toed" stars close by (see Fig. 245). These two small pointers are normally visible in the octant when observations of Vega are taken.

Vega, Deneb (den′-ebb), and Altair (al-tare′) form a right-angle triangle with the right angle at Vega. Altair may be further identified by means of two prominent stars close by and in line with it. Deneb

is the top star in the so-called Northern Cross; the foot of the cross extends between Vega and Altair.

Rasalague (rahs′-ol-ah′gue) forms an equilateral triangle with Vega and Altair; it is less brilliant than either of the others but is occasionally used.

A straight line from Phecda out between the pointers of the Dipper leads to Capella (ka-pel′-lah). Capella may be further identified by means of the Three Kids, three small stars that form a small triangle close by and that are normally visible along with Capella in the octant. Capella is also the brightest star of a prominent pentagon as shown in Fig. 245.

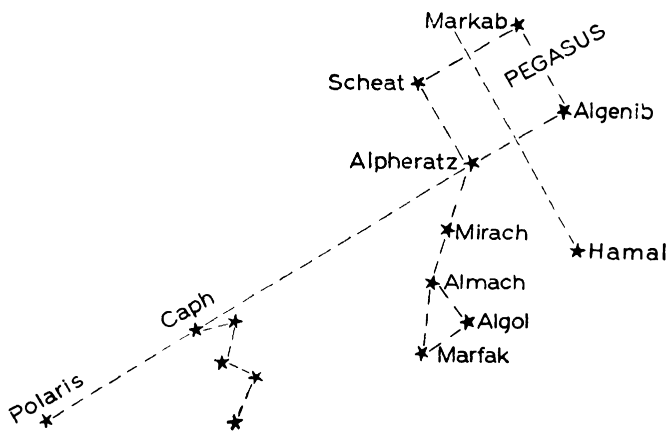


FIG. 246.—Star identification.

Diametrically opposite Capella in this pentagon-shaped figure is a star called El Nath (el-nath′). This star is not often used for navigational purposes, perhaps because of the presence of bright stars near by; but the student should remember that lack of familiarity with the principal bright stars, whether or not listed in the Air Almanac, may lead to confusion.

A straight line from Polaris through Caph leads to Alpheratz (al-feh′-rats) and thence to Algenib (al-gen′-ib). These two stars together with Scheat (shey-at′) and Markab (mar′-kab) form a prominent square of second-magnitude stars called the Square of Pegasus (peg′-a-sus). A tail of stars extends from Alpheratz toward Cassiopeia; the names of the principal stars of this tail are Mirach (my′rack), Almach (al-mack′), and Marfak (mar′-fick). These stars are shown in Fig. 246. Algol (al′-gaul), Marfak, and Almach form a right-angle triangle, with the right-angle at Algol. If the square of Pegasus is bisected as shown in the figure, the bisector will lead to Hamal (ham′-al).

In northern latitudes Scheat and Markab are the first two stars of the Square of Pegasus to rise; a straight line from these first two leads

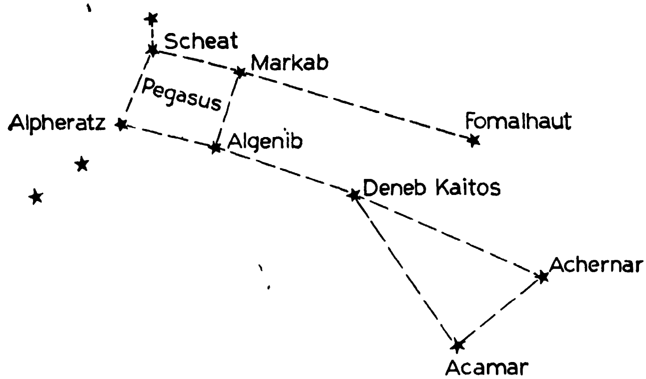


FIG. 247.—Star identification.

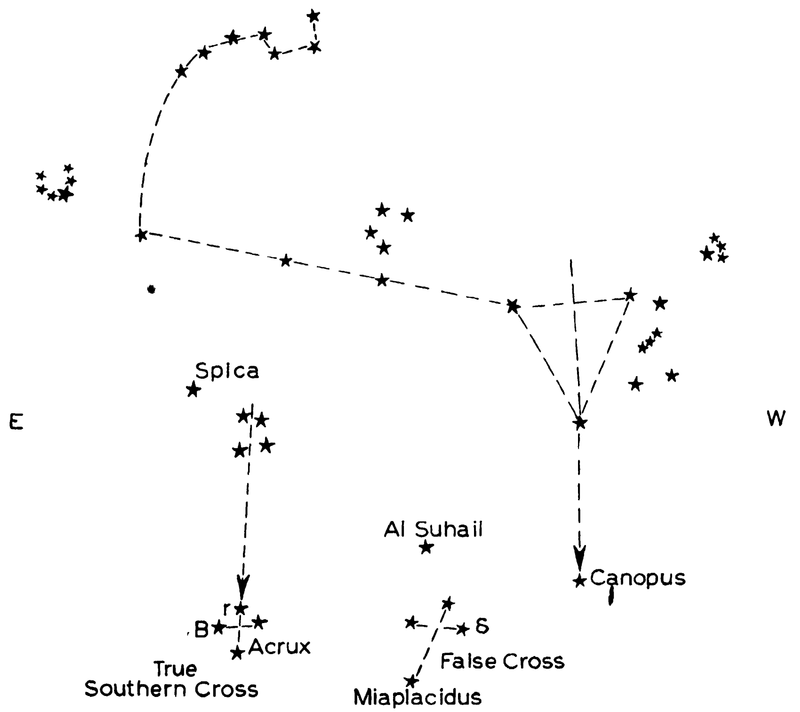


FIG. 248.—Star identification.

to Fomalhaut (foh'-mal-haut'). A line slightly curved from Alpheratz through Algenib leads to Deneb Kaitos (den'-ebb kye'-toas); if this curvature is continued farther south, it leads to the star Achernar

(aye′-cun-nar). Achernar, Deneb Kaitos, and Acamar (ack′-ah-mar) form a right-angle triangle, with the right angle at Acamar.

If the equilateral triangle formed by Betelgeux, Procyon, and Sirius is bisected through the latter star, the bisector will lead to Canopus (cah-no′-pus), one of the brightest stars of the Southern Hemisphere.

If the curvature of the handle of the Big Dipper is continued through Arcturus, it will lead to Spica (spy′-cah); Spica may be further identified by means of the sail-like formation of four stars shown in Fig. 248. The upper part of this sail (gaff) points directly at Spica. Furthermore, if this sail is bisected as shown, the bisector will lead directly to the true Southern Cross. This identification of the true Southern Cross is important because there are two so-called "crosses" in the southern

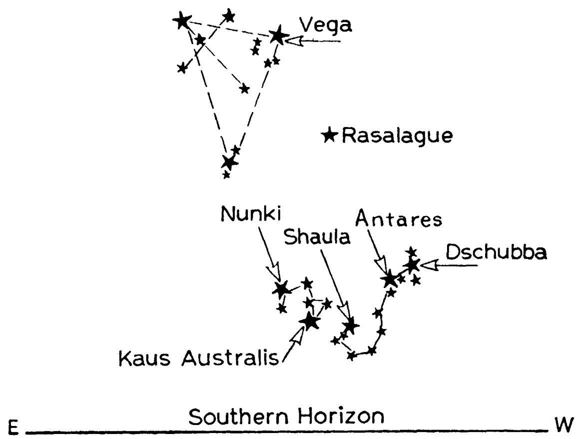


FIG. 249.—Star identification.

sky and the larger and more perfect is not the true Southern Cross. Both constellations are shown in Fig. 248. The bottom star of the Southern Cross is known as Acrux (aye′-crucks), and the bottom star of the false cross is called Miaplacidus (my-ah-plas′-ih-dus). Two other stars of the Southern Cross are used for navigational purposes, β Crucis (beta crew′-sis) and γ Crucis (gamma crew′-sis).

ϵ Argus (ep′-si-lon are′-gus) is the most western star of the false cross; *i.e.*, when the false cross is seen to the southward, this star is on the extreme right. Al Suhail (al soo-hale′) is a short distance north of the false cross, as shown in Fig. 248.

Shortly before Vega and Rasalague cross the observer's meridian, the constellation Scorpio crosses to the southward. This constellation is thought to resemble a dragon with a long curled tail. Three stars, almost in line, form the head of the dragon, and the center of these three is called Dschubba (jub′-a). Three more stars form the top of the back

of which the most brilliant (the center one) is a reddish-colored star called Antares (an-tay′-reez). At the very tip of the tail, which appears to curve up over the back of the dragon, is the navigational star Shaula

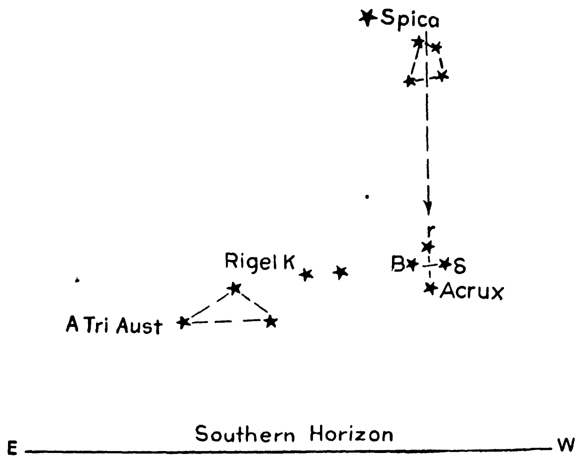


Fig. 250.—Star identification.

(shaw′-la). A little to the eastward is a star of about the same brilliance called Kaus Australis (caws aws-try′-lis). The latter star is the most southern and the brightest of three that form a small wedge. Nunki (nung′-kee) is difficult to identify but is shown in Fig. 249.

Two very bright stars a little east of the true Southern Cross point directly at it. The star farthest from the Southern Cross is Rigil Kentaurus (reej′-ill ken-tow′-rus). Still farther east and somewhat farther south is a broad-based triangle called Triangulum Australis (tri-ang′-u-lum aws-tray′-lis). The stars in this triangle have no familiar names but are represented by Greek letters. α Tri. Aust., the most eastern of these three stars, is sometimes used for navigational purposes.

Enif (enn′-if) is a dim star located between Altair and Markab.

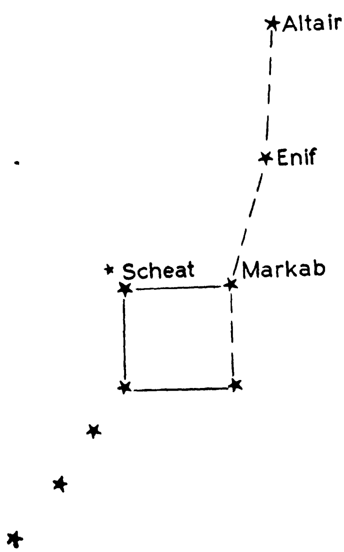


Fig. 251.—Star identification.

Etamin (et′-ah-min) is a star of the same magnitude as Enif and is located between Vega and Kochab.

A straight line through Scheat, Markab, and Fomalhaut leads close by a pair of second-magnitude stars, α and β Grus. The familiar name of α Grus is Al Na′ ir. In point of fact, this straight line cuts through a

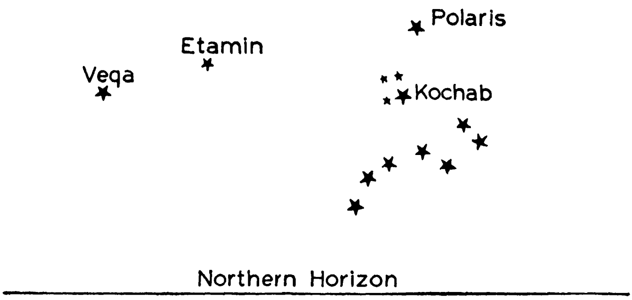


FIG. 252.—Star identification.

group of several stars including α Phoenicus and Peacock as shown in Fig. 253.

Rotation of Earth and Apparent Movement of Stars.—The earth rotates around its true north-south polar axis once every $23^h56^m4^s$. It rotates from west to east; *i.e.*, the eastern horizon appears to drop slowly,

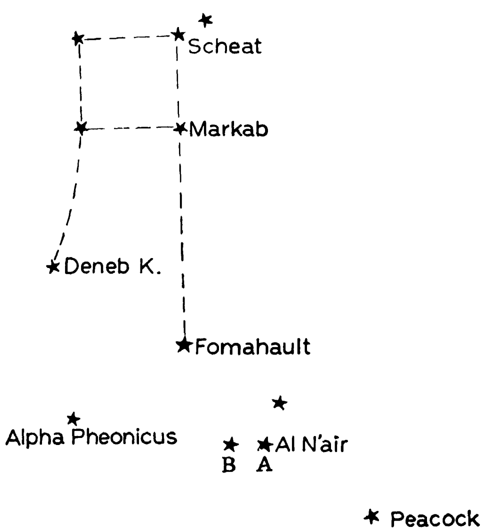


FIG. 253.—Star identification.

and the fixed stars on the celestial sphere rise above it. This is shown in Fig. 254; the earth's south pole is toward the observer.

The direction of rotation is shown in the figure; the star in A, Fig. 254, lies exactly in the eastern horizon. In B, the earth has rotated from west to east; the eastern horizon has dropped, and the star appears above it.

In *C*, the rotation has continued farther and brought about an increase in the star's altitude.

This rotation of the earth is not obvious to an observer; he sees the stars and other celestial bodies rise in the east, pass overhead, and set in the west. This *apparent* rotation of the celestial sphere takes place every $23^h56^m4^s$ and is entirely due to the rotation of the earth about its axis (see Fig. 255).

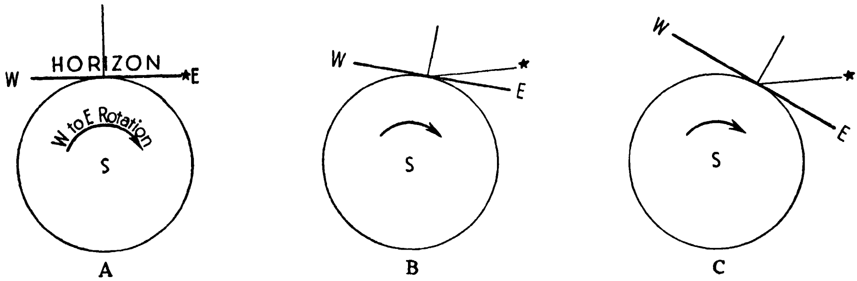


FIG. 254.—Rotation of earth and apparent movement of stars.

A, *B*, and *C*, Fig. 255, show a star rising above the eastern horizon. We shall speak from time to time about this rotation of the celestial sphere; it is to be understood that an *apparent* rotation is being discussed and that this is a result of the earth's rotation about its axis. Any star whose declination is 0° is always located above the earth's equator; any

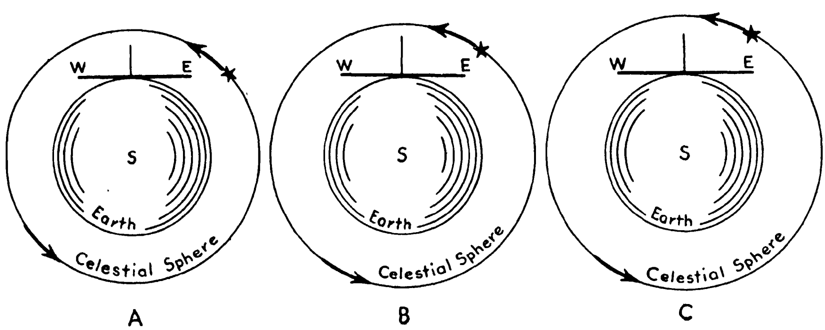


FIG. 255.—Apparent rotation of celestial sphere and heavenly bodies.

star whose declination is 50° N. is always located above the 50th north parallel of latitude, etc.

Effect of the Earth's Rotation on the Apparent Movement of the Sun—GCT.—Navigators all over the world keep their timepieces set to **Greenwich civil time** (GCT), the standard time kept by the master clock in the Greenwich (England) observatory. GCT is based on the *average apparent movement* of the sun. The actual movement of the sun cannot

be used directly as a basis for the measurement of time because its apparent movement is irregular.

The earth rotates on its true north-south axis in $23^h56^m4^s$. This rotation is perfectly regular and produces an apparent rotation of the celestial sphere and stars in this period of time.

The apparent movement of the sun is caused not only by the rotation of the earth but also by its movement around the sun in its orbit. The earth's movement in its orbit is such that it takes the sun approximately 4 min. more than the stars to make one complete circuit around the earth.

Figure 256 shows how the earth's orbital movement produces an apparent movement of the sun. At position *A* the sun is shown exactly in the western horizon; 3 months later the earth's movement to position

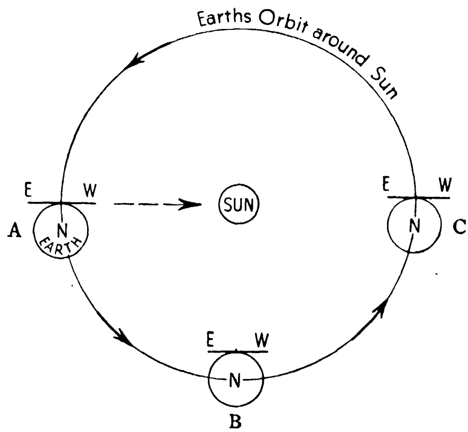


FIG. 256.—Effect of earth's revolution around the sun.

B has caused the sun to rise 90° above the western horizon; after three more months, the earth being at *C*, the sun appears on the eastern horizon. That is, if the earth did not rotate on its axis but only moved around its orbit, the sun would back from west to east 180° in 180 days. This amounts to 1°, or 4 min. a day.

If the movement of the earth in its orbit were as regular as its rotation about its axis, the length of the solar day would never vary and could be used to regulate timepieces. The earth, however, moves in an elliptical orbit; and, while its rate of travel is uniform when expressed in miles per minute, its angular rate of travel in its orbit varies from season to season. When the earth is relatively close to the sun, its angular velocity is highest and at this time of year the sun appears to travel through the heavens at a slightly faster rate of speed then it does when the earth is at either extremity of its orbit. Owing to the eccentricity of the earth's path around the sun, the average 4-min. interval mentioned

above sometimes amounts to but 3½ min. per day while at other times it is as high as 4½ min.

Summary.—The apparent movement of the sun, as we see it, is brought about by two movements of the earth, one about its axis and the other around the sun. What might otherwise be a solar day of $23^h56^m04^s$ becomes a day of $23^h59^m30^s$ to $24^h00^m30^s$. Since the length of the true solar day is a variable quantity, GCT and other standard times are based on the average apparent movement of the sun, *i.e.*, 24 hr. a day. The Greenwich day commences at midnight, and the hours are numbered from 1 to 24.

Use of GCT.—The celestial sphere appears to rotate about the earth, and in so doing the celestial zero meridian Aries moves with it. For international uniformity and convenience the position of this meridian with respect to Greenwich is tabulated against GCT.

GHA of the Aries Meridian and Stars.—If the position of the Aries meridian is known, the position of any star in the heavens may be determined relative to the earth because the SHA and declination of the stars are fixed. If, for example, at 0200 the meridian of Aries is 40° west of the Greenwich meridian, any star on the Aries meridian is likewise 40° west of Greenwich. At this same instant any star whose SHA is 50° must be located somewhere above the 90th west longitude meridian on the earth, because the star by the definition of SHA is located 50° west of Aries. If the declination of this latter star is 50°N., it must be located not only above the 90th west longitude meridian but also above the intersection of 90°W. Long. and 50°N. Lat. Such a point on the earth directly underneath a star is called a **subastral point,** and it would be around such a point that a circle of equal altitude would be drawn.

The position of the meridian of Aries is tabulated in the American Air Almanac for every 10-min. interval of the Greenwich civil day. A 12-hr. portion of such a tabulation is shown in Fig. 257 under the heading GHA of Aries. The term GHA stands for Greenwich hour angle and designates the westward arc from Greenwich to the Aries meridian. At 1100 GCT according to this tabulation the meridian of Aries is 7°44′ west of Greenwich; at 1150 GCT the meridian is 20°16′ west of Greenwich.

GCT	♈ GHA
h m	° ′
0 00	202 17
10	204 47
20	207 18
30	209 48
40	212 18
50	214 49
1 00	217 19
10	219 50
20	222 20
30	224 50
40	227 21
50	229 51
2 00	232 22
10	234 52
20	237 23
30	239 53
40	242 23
50	244 54
3 00	247 24
10	249 55
20	252 25
30	254 55
40	257 26
50	259 56
4 00	262 27
10	264 57
20	267 27
30	269 58
40	272 28
50	274 59
5 00	277 29
10	280 00
20	282 30
30	285 00
40	287 31
50	290 01
6 00	292 32
10	295 02
20	297 32
30	300 03
40	302 33
50	305 04
7 00	307 34
10	310 04
20	312 35
30	315 05
40	317 36
50	320 06
8 00	322 36
10	325 07
20	327 37
30	330 08
40	332 38
50	335 09
9 00	337 39
10	340 09
20	342 40
30	345 10
40	347 41
50	350 11
10 00	352 41
10	355 12
20	357 42
30	0 13
40	2 43
50	5 13
11 00	7 44
10	10 14
20	12 45
30	15 15
40	17 46
50	20 16
12 00	22 46

FIG. 257.—GHA of Aries Apr. 15, 1943.

PROBLEMS

1. According to this tabulation, how far west of Greenwich was the meridian of Aries at 1110 GCT; at 1120 GCT; at 1115 GCT?

The westward angle from the Greenwich meridian to the celestial meridian containing a star is known as the **GHA of the star.** This is obtained by adding the star's SHA to the GHA of Aries.

2. According to the tabulation in Figs. 238 and 257, what were the GHA and declination of the star Regulus at 0130 GCT?

Procedure:	GHA of Aries at 0130 GCT	224°50′
	SHA of Regulus	208 40
		433 30
		Less 360
	GHA of Regulus	73°30′
	Dec. of Regulus	12°15′N.

At this instant the subastral point of Regulus was 12°15′N. Lat., 73°30′W. Long.

3. What were the subastral points of Procyon and Sirius at this same time?
4. What were the subastral points of Acrux, Pollux, and Rigel at 0150 GCT?

GHA of Solar-system Bodies.—The sun, moon, and planets do not occupy fixed positions in the heavens; their relative nearness to the earth coupled with orbital movements causes them to shift position slightly from day to day. Their positions with respect to the meridian of Aries and the celestial equator vary and because of this their declinations and GHA's are tabulated directly without reference to the meridian of Aries. This daily tabulation of their positions makes them somewhat easier to use than the stars. Typical Air Almanac pages are reproduced in Fig. 258*a* and *b*. They contain the GHA of Aries and the GHA and declination of those solar-system bodies available for navigational purposes.

PROBLEMS

1. What are the GHA and declination of the planet Jupiter at 0610 GCT?
Ans.: GHA = 186°35′. Dec. = 22°46′N.
2. What are the GHA and declination of the sun, Venus, Jupiter, Mars, and the moon at 0920 GCT?

Explanation of Declination Change—Solar-system Bodies.—Figure 258 shows that the declination of some of the solar-system bodies changes more rapidly than that of others. Figure 259 shows why this occurs.

The orbit of Venus is inside that of the earth; the orbits of the other navigational planets are outside. The declination of any of the solar-system bodies depends on where it is seen from the earth against the celestial sphere. Thus, with the earth at A, a planet at B is seen north of the celestial equator AX. A planet at C appears against the celestial

GREENWICH A. M. 1943 APRIL 15 (THURSDAY)

GCT	☉ SUN GHA	☉ SUN Dec.	♈ GHA	VENUS -3.5 GHA	VENUS -3.5 Dec.	MARS 1.1 GHA	MARS 1.1 Dec.	JUPITER -1.6 GHA	JUPITER -1.6 Dec.	☾ MOON GHA	☾ MOON Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
0 00	179 55	N 9 22	202 17	145 46	N21 03	231 28	S13 24	93 51	N22 46	60 00	N14 34
10	182 25		204 47	148 16		233 58		96 21		62 25	32
20	184 55		207 18	150 46		236 28		98 52		64 51	31
30	187 25	· ·	209 48	153 16	· ·	238 58	· ·	101 22	· ·	67 16	· 30
40	189 55		212 18	155 46		241 28		103 52		69 42	29
50	192 25		214 49	158 16		243 58		106 23		72 07	28
00	194 55	N 9 23	217 19	160 45	N21 04	246 28	S13 23	108 53	N22 46	74 32	N14 27
10	197 25		219 50	163 15		248 59		111 24		76 58	25
20	199 55		222 20	165 45		251 29		113 54		79 23	24
30	202 25	· ·	224 50	168 15	· ·	253 59	· ·	116 24	· ·	81 48	· 23
40	204 55		227 21	170 45		256 29		118 55		84 14	22
50	207 25		229 51	173 15		258 59		121 25		86 39	21
2 00	209 55	N 9 24	232 22	175 45	N21 04	261 29	S13 23	123 55	N22 46	89 05	N14 20
10	212 25		234 52	178 15		263 59		126 26		91 30	18
20	214 55		237 23	180 45		266 29		128 56		93 55	17
30	217 25	· ·	239 53	183 14	· ·	268 59	·	131 27	· ·	96 21	· 16
40	219 55		242 23	185 44		271 29		133 57		98 46	15
50	222 25		244 54	188 14		274 00		136 27		101 11	14
3 00	224 55	N 9 25	247 24	190 44	N21 05	276 30	S13 22	138 58	N22 46	103 37	N14 13
10	227 25		249 55	193 14		279 00		141 28		106 02	11
20	229 55		252 25	195 44		281 30		143 58		108 28	10
30	232 25	· ·	254 55	198 14	· ·	284 00	· ·	146 29	· ·	110 53	· 09
40	234 55		257 26	200 44		286 30		148 59		113 18	08
50	237 25		259 56	203 14		289 00		151 29		115 44	07
4 00	239 55	N 9 26	262 27	205 44	N21 06	291 30	S13 21	154 00	N22 46	118 09	N14 05
10	242 25		264 57	208 13		294 00		156 30		120 34	04
20	244 55		267 27	210 43		296 31		159 01		123 00	03
30	247 26	· ·	269 58	213 13	· ·	299 01	· ·	161 31	· ·	125 25	· 02
40	249 56		272 28	215 43		301 31		164 01		127 51	14 01
50	252 26		274 59	218 13		304 01		166 32		130 16	13 59
5 00	254 56	N 9 27	277 29	220 43	N21 07	306 31	S13 21	169 02	N22 46	132 41	N13 58
10	257 26		280 00	223 13		309 01		171 32		135 07	57
20	259 56		282 30	225 43		311 31		174 03		137 32	56
30	262 26	· ·	285 00	228 13	· ·	314 01	· ·	176 33	· ·	139 58	· 55
40	264 56		287 31	230 43		316 31		179 03		142 23	53
50	267 26		290 01	233 12		319 02		181 34		144 48	52
6 00	269 56	N 9 28	292 32	235 42	N21 07	321 32	S13 20	184 04	N22 46	147 14	N13 51
10	272 26		295 02	238 12		324 02		186 35		149 39	50
20	274 56		297 32	240 42		326 32		189 05		152 04	49
30	277 26	· ·	300 03	243 12	· ·	329 02	· ·	191 35	· ·	154 30	· 47
40	279 56		302 33	245 42		331 32		194 06		156 55	46
50	282 26		305 04	248 12		334 02		196 36		159 21	45
7 00	284 56	N 9 29	307 34	250 42	N21 08	336 32	S13 19	199 06	N22 46	161 46	N13 44
10	287 26		310 04	253 12		339 02		201 37		164 11	42
20	289 56		312 35	255 41		341 32		204 07		166 37	41
30	292 26	· ·	315 05	258 11	· ·	344 03	· ·	206 37	· ·	169 02	· 40
40	294 56		317 36	260 41		346 33		209 08		171 28	39
50	297 26		320 06	263 11		349 03		211 38		173 53	38
8 00	299 56	N 9 29	322 36	265 41	N21 09	351 33	S13 19	214 09	N22 46	176 18	N13 36
10	302 26		325 07	268 11		354 03		216 39		178 44	35
20	304 56		327 37	270 41		356 33		219 09		181 09	34
30	307 26	· ·	330 08	273 11	· ·	359 03	· ·	221 40	· ·	183 34	· 33
40	309 56		332 38	275 41		1 33		224 10		186 00	31
50	312 26		335 09	278 11		4 03		226 40		188 25	30
9 00	314 56	N 9 30	337 39	280 40	N21 10	6 34	S13 18	229 11	N22 46	190 51	N13 29
10	317 26		340 09	283 10		9 04		231 41		193 16	28
20	319 56		342 40	285 40		11 34		234 12		195 41	26
30	322 26	· ·	345 10	288 10	· ·	14 04	· ·	236 42	· ·	198 07	· 25
40	324 56		347 41	290 40		16 34		239 12		200 32	24
50	327 26		350 11	293 10		19 04		241 43		202 58	23
10 00	329 56	N 9 31	352 41	295 40	N21 11	21 34	S13 18	244 13	N22 46	205 23	N13 21
10	332 26		355 12	298 10		24 04		246 43		207 48	20
20	334 56		357 42	300 40		26 34		249 14		210 14	19
30	337 26	· ·	0 13	303 10	· ·	29 05	· ·	251 44	· ·	212 39	· 18
40	339 57		2 43	305 39		31 35		254 14		215 05	16
50	342 27		5 13	308 09		34 05		256 45		217 30	15
11 00	344 57	N 9 32	7 44	310 39	N21 11	36 35	S13 17	259 15	N22 46	219 55	N13 14
10	347 27		10 14	313 09		39 05		261 46		222 21	12
20	349 57		12 45	315 39		41 35		264 16		224 46	11
30	352 27	· ·	15 15	318 09	· ·	44 05	· ·	266 46	· ·	227 12	· 10
40	354 57		17 46	320 39		46 35		269 17		229 37	09
50	357 27		20 16	323 09		49 05		271 47		232 02	07
12 00	359 57	N 9 33	22 46	325 39	N21 12	51 35	S13 16	274 17	N22 46	234 28	N13 06

☾ Par.

Alt. °	Corr. ′ +
0	
6	55
12	54
16	53
20	52
22	51
25	50
27	49
29	48
31	47
33	46
35	45
37	44
39	43
40	42
42	41
43	40
45	39
46	38
48	37
49	36
50	35
52	34
53	33
54	32
56	31
57	30
58	29
59	28
61	27
62	26
63	25
64	24
65	23
66	22
68	21
69	20
70	19
71	18
72	17
73	16
74	15
75	14
76	13
77	12
78	11
80	10

SD ′ ☉ 16

SD ′ ☾ 15

Corr. HA ☾

Int m	Corr ′
0	0
10	

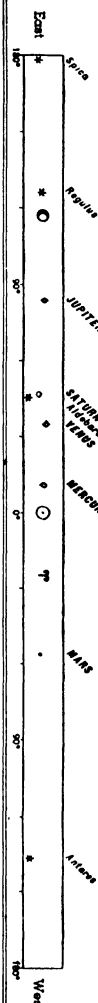


FIG. 258a.—Typical American Air Almanac page—0 to 12 hours GCT.

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GCT	☉ SUN GHA	☉ SUN Dec.	♈ GHA	VENUS -3.5 GHA	VENUS Dec.	MARS 1.1 GHA	MARS Dec.	JUPITER -1.6 GHA	JUPITER Dec.	☾ MOON GHA	☾ MOON Dec.
h m	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
12 00	359 57	N 9 33	22 46	325 39	N21 12	51 35	S13 16	274 17	N22 46	234 28	N13 06
10	2 27		25 17	328 09		54 06		276 48		236 53	05
20	4 57		27 47	330 38		56 36		279 18		239 19	04
30	7 27	· ·	30 18	333 08	· ·	59 06	· ·	281 48	· ·	241 44	· 02
40	9 57		32 48	335 38		61 36		284 19		244 09	01
50	12 27		35 18	338 08		64 06		286 49		246 35	13 00
13 00	14 57	N 9 34	37 49	340 38	N21 13	66 36	S13 16	289 20	N22 46	249 00	N12 58
10	17 27		40 19	343 08		69 06		291 50		251 26	57
20	19 57		42 50	345 38		71 36		294 20		253 51	56
30	22 27	· ·	45 20	348 08	· ·	74 06	· ·	296 51	· ·	256 16	· 54
40	24 57		47 50	350 38		76 37		299 21		258 42	53
50	27 27		50 21	353 07		79 07		301 51		261 07	52
14 00	29 57	N 9 35	52 51	355 37	N21 14	81 37	S13 15	304 22	N22 46	263 33	N12 51
10	32 27		55 22	358 07		84 07		306 52		265 58	49
20	34 57		57 52	0 37		86 37		309 22		268 23	48
30	37 27	· ·	60 23	3 07	· ·	89 07	· ·	311 53	· ·	270 49	· 47
40	39 57		62 53	5 37		91 37		314 23		273 14	45
50	42 27		65 23	8 07		94 07		316 54		275 40	44
15 00	44 57	N 9 36	67 54	10 37	N21 14	96 37	S13 14	319 24	N22 46	278 05	N12 43
10	47 27		70 24	13 07		99 08		321 54		280 30	41
20	49 57		72 55	15 37		101 38		324 25		282 56	40
30	52 27	· ·	75 25	18 06	· ·	104 08	· ·	326 55	· ·	285 21	· 39
40	54 57		77 55	20 36		106 38		329 25		287 47	37
50	57 27		80 26	23 06		109 08		331 56		290 12	36
16 00	59 57	N 9 37	82 56	25 36	N21 15	111 38	S13 14	334 26	N22 46	292 37	N12 35
10	62 27		85 27	28 06		114 08		336 56		295 03	33
20	64 57		87 57	30 36		116 38		339 27		297 28	32
30	67 27	· ·	90 27	33 06	· ·	119 08	· ·	341 57	· ·	299 54	· 31
40	69 57		92 58	35 36		121 38		344 28		302 19	29
50	72 28		95 28	38 06		124 09		346 58		304 44	28
17 00	74 58	N 9 38	97 59	40 36	N21 16	126 39	S13 13	349 28	N22 46	307 10	N12 27
10	77 28		100 29	43 05		129 09		351 59		309 35	25
20	79 58		102 59	45 35		131 39		354 29		312 01	24
30	82 28	· ·	105 30	48 05	· ·	134 09	· ·	356 59	· ·	314 26	· 23
40	84 58		108 00	50 35		136 39		359 30		316 51	21
50	87 28		110 31	53 05		139 09		2 00		319 17	20
18 00	89 58	N 9 38	113 01	55 35	N21 17	141 39	S13 13	4 31	N22 46	321 42	N12 19
10	92 28		115 32	58 05		144 09		7 01		324 08	17
20	94 58		118 02	60 35		146 40		9 31		326 33	16
30	97 28	· ·	120 32	63 05	· ·	149 10	· ·	12 02	· ·	328 58	· 15
40	99 58		123 03	65 34		151 40		14 32		331 24	13
50	102 28		125 33	68 04		154 10		17 02		333 49	12
19 00	104 58	N 9 39	128 04	70 34	N21 17	156 40	S13 12	19 33	N22 45	336 15	N12 11
10	107 28		130 34	73 04		159 10		22 03		338 40	09
20	109 58		133 04	75 34		161 40		24 33		341 05	08
30	112 28	· ·	135 35	78 04	· ·	164 10	· ·	27 04	· ·	343 31	· 07
40	114 58		138 05	80 34		166 40		29 34		345 56	05
50	117 28		140 36	83 04		169 11		32 05		348 22	04
20 00	119 58	N 9 40	143 06	85 34	N21 18	171 41	S13 11	34 35	N22 45	350 47	N12 03
10	122 28		145 36	88 04		174 11		37 05		353 12	01
20	124 58		148 07	90 33		176 41		39 36		355 38	12 00
30	127 28	· ·	150 37	93 03	· ·	179 11	· ·	42 06	· ·	358 03	· 11 59
40	129 58		153 08	95 33		181 41		44 36		0 29	57
50	132 28		155 38	98 03		184 11		47 07		2 54	56
21 00	134 58	N 9 41	158 09	100 33	N21 19	186 41	S13 11	49 37	N22 45	5 19	N11 54
10	137 28		160 39	103 03		189 11		52 07		7 45	53
20	139 58		163 09	105 33		191 41		54 38		10 10	52
30	142 28	· ·	165 40	108 03	· ·	194 12	· ·	57 08	· ·	12 36	· 50
40	144 58		168 10	110 33		196 42		59 39		15 01	49
50	147 28		170 41	113 03		199 12		62 09		17 26	47
22 00	149 58	N 9 42	173 11	115 32	N21 20	201 42	S13 10	64 39	N22 45	19 52	N11 46
10	152 28		175 41	118 02		204 12		67 10		22 17	45
20	154 58		178 12	120 32		206 42		69 40		24 43	43
30	157 28	· ·	180 42	123 02	· ·	209 12	· ·	72 10	· ·	27 08	· 42
40	159 58		183 13	125 32		211 42		74 41		29 34	41
50	162 28		185 43	128 02		214 12		77 11		31 59	39
23 00	164 59	N 9 43	188 13	130 32	N21 20	216 43	S13 09	79 41	N22 45	34 24	N11 38
10	167 29		190 44	133 02		219 13		82 12		36 50	36
20	169 59		193 14	135 32		221 43		84 42		39 15	35
30	172 29	· ·	195 45	138 01	· ·	224 13	· ·	87 13	· ·	41 41	· 34
40	174 59		198 15	140 31		226 43		89 43		44 06	32
50	177 29		200 46	143 01		229 13		92 13		46 31	31
24 00	179 59	N 9 44	203 16	145 31	N21 21	231 43	S13 09	94 44	N22 45	48 57	N11 29

Lat.	Sunrise	Twil.	Moonrise	Diff.
N °	h m	m	h m	m
60	4 47	48	12 50	74
58	52	45	12 58	72
56	4 57	41	13 05	69
54	5 02	39	11	68
52	06	37	17	65
50	10	35	22	64
45	17	31	32	62
40	24	29	41	59
35	30	27	49	56
30	34	25	13 56	54
20	43	23	14 07	51
10	50	22	18	48
0	5 57	21	27	45
10	6 04	22	36	43
20	11	22	46	40
30	18	24	14 58	37
35	23	26	15 05	34
40	27	27	12	33
45	33	29	21	30
50	40	32	31	27
52	43	33	36	26
54	46	35	41	25
56	50	37	47	23
58	54	39	15 54	20
60	6 59	42	16 01	18
S				

Lat.	Sunset	Twil.	Moonset	Diff.
N °	h m	m	h m	m
60	19 15	47	3 49	20
58	09	43	41	21
56	04	40	33	24
54	19 00	38	27	25
52	18 56	36	21	27
50	52	34	16	28
45	44	30	3 04	31
40	37	29	2 54	34
35	32	27	46	35
30	26	25	38	38
20	18	23	25	41
10	10	22	14	43
0	18 04	21	2 03	46
10	17 57	22	1 53	48
20	50	23	41	51
30	42	24	28	54
35	38	26	20	56
40	33	28	12	58
45	27	30	1 02	60
50	20	32	0 49	63
52	17	34	44	64
54	13	36	37	66
56	10	37	30	68
58	05	39	22	70
60	17 01	42	0 13	72
S				

FIG. 258*b*.—Typical American Air Almanac page—12 to 24 hours GCT.

sphere below the celestial equator. Their declinations will change as the earth moves around the sun in its orbit and also as they themselves move in their own orbits. The outer planets require several years to complete one circuit around the sun; Venus requires but 225 days to complete its orbit. Hence, the rate of declination change may be expected to vary in each instance.

Interpolation of GHA.—The GHA of a body determines the longitude of the subastral, subsolar, or sublunar point. Since celestial bodies move through the sky to the westward at the rate of about 15′ Long. per minute of time, the GHA of the body for the *precise GCT of observation* must of necessity be determined. An approximate GHA would result in

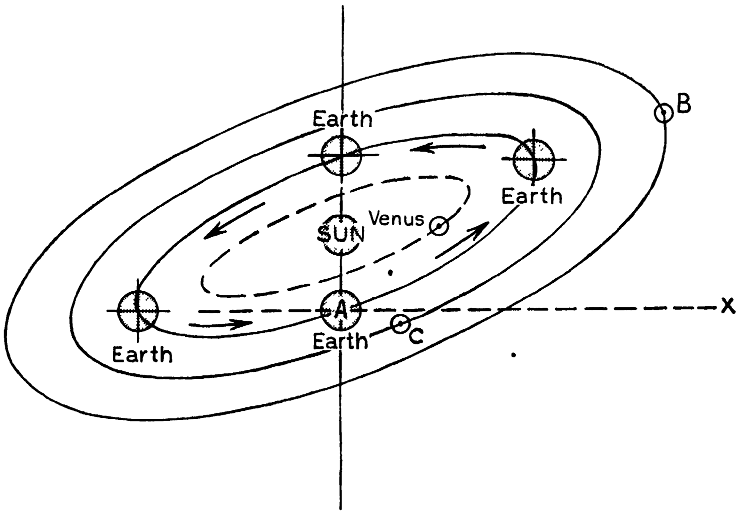


Fig. 259.—Declination change of solar-system bodies.

an erroneous subastral or subsolar point, and the circle of equal altitude would be drawn far out of position. The interpolation table (Fig. 260) is used when the time of observation does not coincide with one of the times given directly in the Air Almanac page (Figs. 258*a* and *b*).

The correction to be applied to the tabulated value of GHA on the daily Almanac sheet is shown, under the column headed Corr., opposite the elapsed time past the tabulated GCT. Thus, in the case of the sun, planets, or meridian of Aries, a correction of 1°30′ is added to the tabulated GHA when the time of observation is 5^m58^s to 6^m1^s past the GCT shown on the daily page. In the case of the moon, a correction of 1°30′ is added when the time of observation is 6^m11^s to 6^m14^s past the GCT shown on the daily page. In the event the correction is desired for an interval shown in boldface type in the interpolation table (Fig. 260), the correction value to the right and above the boldface entry is used. Thus,

if an observation of the moon is taken at $06^h02^m55^s$ GCT, a correction of 0°42′ is to be added to the tabulated GHA shown opposite 0600 on the daily sheet.

INTERPOLATION OF GHA

SUN, PLANETS, ♈

Int. m s	Corr. ° ′	Int. m s	Corr. ° ′	Int. m s	Corr. ° ′
00 00	0 00	03 17	0 50	06 37	1 40
01	0 01	21	0 51	41	1 41
05	0 02	25	0 52	45	1 42
09	0 03	29	0 53	49	1 43
13	0 04	33	0 54	53	1 44
17	0 05	37	0 55	57	1 45
21	0 06	41	0 56	07 01	1 46
25	0 07	45	0 57	05	1 47
29	0 08	49	0 58	09	1 48
33	0 09	53	0 59	13	1 49
37	0 10	57	1 00	17	1 50
41	0 11	04 01	1 01	21	1 51
45	0 12	05	1 02	25	1 52
49	0 13	09	1 03	29	1 53
53	0 14	13	1 04	33	1 54
57	0 15	17	1 05	87	1 55
01 01	0 16	21	1 06	41	1 56
05	0 17	25	1 07	45	1 57
09	0 18	29	1 08	49	1 58
13	0 19	33	1 09	53	1 59
17	0 20	37	1 10	57	2 00
21	0 21	41	1 11	08 01	2 01
25	0 22	45	1 12	05	2 02
29	0 23	49	1 13	09	2 03
33	0 24	53	1 14	13	2 04
37	0 25	57	1 15	17	2 05
41	0 26	05 01	1 16	21	2 06
45	0 27	05	1 17	25	2 07
49	0 28	09	1 18	29	2 08
53	0 29	13	1 19	33	2 09
57	0 30	17	1 20	37	2 10
02 01	0 31	21	1 21	41	2 11
05	0 32	25	1 22	45	2 12
09	0 33	29	1 23	49	2 13
13	0 34	33	1 24	53	2 14
17	0 35	37	1 25	57	2 15
21	0 36	41	1 26	09 01	2 16
25	0 37	45	1 27	05	2 17
29	0 38	49	1 28	09	2 18
33	0 39	53	1 29	13	2 19
37	0 40	57	1 30	17	2 20
41	0 41	06 01	1 31	21	2 21
45	0 42	05	1 32	25	2 22
49	0 43	09	1 33	29	2 23
53	0 44	13	1 34	33	2 24
57	0 45	17	1 35	37	2 25
03 01	0 46	21	1 36	41	2 26
05	0 47	25	1 37	45	2 27
09	0 48	29	1 38	49	2 28
13	0 49	33	1 39	53	2 29
17	0 50	37	1 40	57	2 30
21		41		10 00	

MOON

Int. m s	Corr. ° ′	Int. m s	Corr. ° ′	Int. m s	Corr. ° ′
00 00	0 00	03 20	0 49	06 39	1 37
02	0 01	24	0 50	43	1 38
06	0 02	29	0 51	47	1 39
10	0 03	33	0 52	52	1 40
14	0 04	37	0 53	56	1 41
18	0 05	41	0 54	07 00	1 42
22	0 06	45	0 55	04	1 43
26	0 07	49	0 56	08	1 44
31	0 08	53	0 57	12	1 45
35	0 09	58	0 58	16	1 46
39	0 10	04 02	0 59	20	1 47
43	0 11	06	1 00	25	1 48
47	0 12	10	1 01	29	1 49
51	0 13	14	1 02	33	1 50
55	0 14	18	1 03	37	1 51
01 00	0 15	22	1 04	41	1 52
04	0 16	27	1 05	45	1 53
08	0 17	31	1 06	49	1 54
12	0 18	35	1 07	54	1 55
16	0 19	39	1 08	58	1 56
20	0 20	43	1 09	08 02	1 57
24	0 21	47	1 10	06	1 58
29	0 22	51	1 11	10	1 59
33	0 23	56	1 12	14	2 00
37	0 24	05 00	1 13	18	2 01
41	0 25	04	1 14	23	2 02
45	0 26	08	1 15	27	2 03
49	0 27	12	1 16	31	2 04
53	0 28	16	1 17	35	2 05
58	0 29	20	1 18	39	2 06
02 02	0 30	25	1 19	43	2 07
06	0 31	29	1 20	47	2 08
10	0 32	33	1 21	52	2 09
14	0 33	37	1 22	56	2 10
18	0 34	41	1 23	09 00	2 11
22	0 35	45	1 24	04	2 12
26	0 36	49	1 25	08	2 13
31	0 37	54	1 26	12	2 14
35	0 38	58	1 27	16	2 15
39	0 39	06 02	1 28	21	2 16
43	0 40	06	1 29	25	2 17
47	0 41	10	1 30	29	2 18
51	0 42	14	1 31	33	2 19
55	0 43	18	1 32	37	2 20
03 00	0 44	23	1 33	41	2 21
04	0 45	27	1 34	45	2 22
08	0 46	31	1 35	50	2 23
12	0 47	35	1 36	54	2 24
16	0 48	39	1 37	58	2 25
20	0 49	43		10 00	
24					

Correction to be added to GHA for interval of GCT

FIG. 260.—American Air Almanac interpolation table.

PROBLEMS

1. What are the GHA and declination of the moon at $02^h15^m27^s$ GCT?

Procedure: GHA of moon for 02^h10^m GCT 91°30′
Corr. for 5^m27^s 1 19
GHA of moon 92°49′
Dec. of moon 14°18′N.

2. What are the GHA and declination of the following bodies at $10^h13^m33^s$ GCT, Apr. 15, 1943: Venus, sun, Mars, Jupiter, and moon?

Summary.—The altitude of a celestial body is measured above the observer's horizon. This horizon is a plane tangent to the earth at the observer's feet; the point directly overhead is 90° above this horizon and is called the observer's **zenith.**

We have already discussed how to locate a subastral, subsolar, or sublunar point. At such a point an observer must obtain a 90° angle of the body in question. Under this condition his zenith and the position of the body in the celestial sphere must coincide. If the observer's zenith is 10° removed from the position of the celestial body, an altitude of but 80° would be observed. Such a 10° displacement of the zenith can occur only when the observer is 10° of a great circle away from the subsolar or astral point.

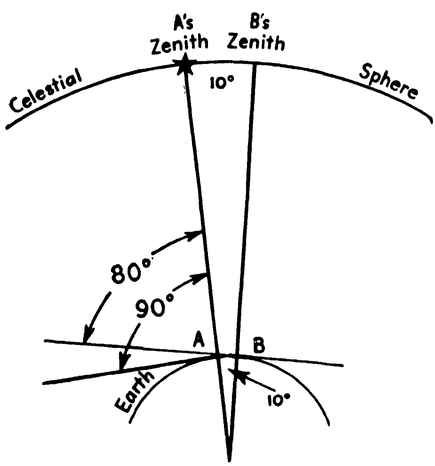


FIG. 261.—Change of altitude with change of zenith.

This is shown in Fig. 212, where an observer at A (the subastral point) observes a 90° angle of a star. An observer at B obtains an 80° altitude of the *same* star, which indicates that his zenith is 10° removed from the star. If his zenith is 10° from the star, his position on the earth is 10° from the subastral point, for the arc separating their zeniths is the same as the great-circle arc separating them on the earth. A degree of a great circle is 60 nautical miles; observer B is on a circle of equal altitude everywhere 600 nautical miles distant from the subastral point A.

That is, it is possible to establish a circle of equal altitude by observing the altitude of the star above the horizon and using this information in conjunction with its subastral point. In practice, however, complete circles of equal altitude are seldom used, for the radius of these circles is usually so great that certain portions could not possibly indicate the plane's position. A small portion of such a circle is practically a straight line and is known as a *line of position.* The detailed steps taken by the navigator to determine such a portion of a circle of equal altitude will be described in the following chapter.

CHAPTER IX

PRACTICE OF CELESTIAL NAVIGATION

Circle of Equal Altitude—Limitations.—Chart size and chart distortion both impose limitations on the use of large circles of equal altitude. When an observed altitude is low, the subsolar or astral point is generally too far distant to be plotted on the chart. Besides, when large circles are correctly plotted on a distorted chart, the distortion factor must be taken into consideration—an involved and time-consuming task in flight. Because of this, the use of equal-altitude circles as a means of showing all possible positions of an aircraft is limited to occasions when the observed altitude is high. Little error is introduced if the observed altitude is above 88°, but accurate determination of such high altitudes calls for more than average skill.

Celestial Lines of Position.—Fortunately, navigators are seldom concerned with the possibility of being located on either side of a circle

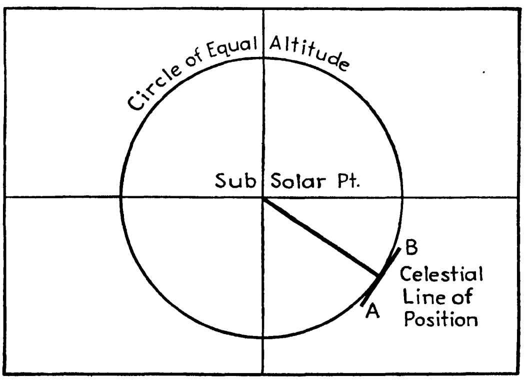


FIG. 262.—Circle of equal altitude and celestial line of position.

hundreds or thousands of miles in diameter. Since the plane's position is always known within certain general limits, it is necessary to construct only that portion of the circle reasonably close to the plane's approximate position. Such a line is called a **celestial line of position.**

The curvature of this section of the circle is neglected; it is drawn as a short straight line at right angles to the true bearing of the celestial body, as shown by the line AB in Fig. 262.

When the subsolar point is not used, the navigator assumes his plane to be located at some convenient point near his approximate position.

The true bearing and altitude of the celestial body at the assumed position are determined for the precise GCT of observation. The actual altitude is then compared with the calculated altitude. In this manner the plane's position circle is located either inside or outside the one through the assumed position—rather than at a given distance from the subsolar or astral point.

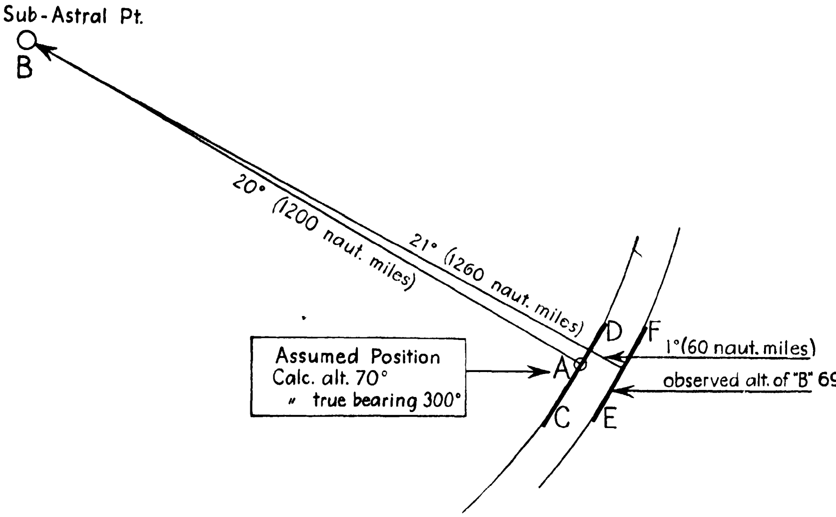


FIG. 263.—Use of assumed position vs. subastral point.

Figure 263 will clarify this procedure. The navigator assumed the plane to be at A and calculated the true bearing and altitude of the star B as it occurred at the assumed position. The data are tabulated below:

True Bearing	Altitude
300°	70°

Actual observation showed that the altitude was 69°. It can be reasoned that the plane was on a circle of equal altitude whose radius was $21° \times 60$, or 1,260 nautical miles from the subastral point. It may also be reasoned that the plane was on a circle of equal altitude 60 miles outside that passing through the assumed position. The latter line of reasoning and the procedure incident to it are followed by modern navigators. In Fig. 263 the line *CD*—at right angles to the true bearing of the body—is a portion of the calculated circle of equal altitude through *assumed position A*. The line *EF* is a portion of the circle of equal altitude containing the *plane's position*. Since the plane is known to be near position *A*, the line *EF* is sufficient to show all reasonable positions of the plane.

Plotting Celestial Lines of Position.—The following problems in plotting celestial lines of position will prove helpful.

PROBLEMS

1. By observation the sun is 60° above the horizon. Navigation tables show that the sun is 59° above the horizon at the assumed position *A* and that its true bearing is 110° true.

Required: Show the celestial line of position on which the plane is located.

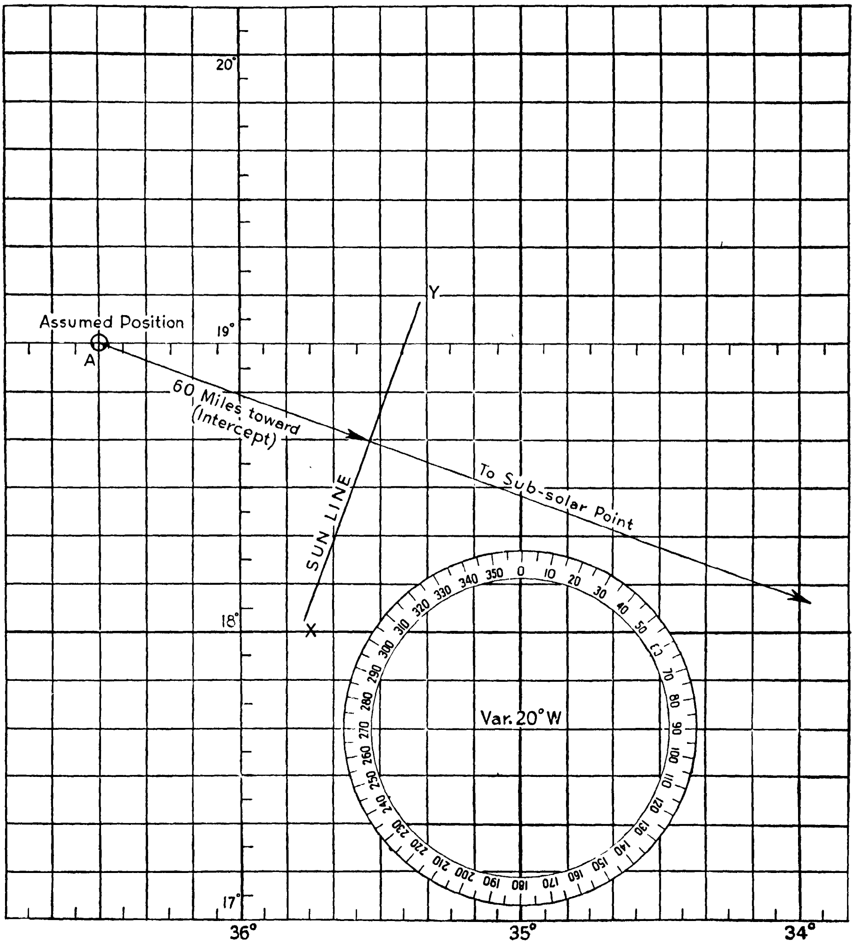


FIG. 264.—Plotting celestial lines of position Prob. 1, 2, and 3.

Procedure: From the assumed position *A* in Fig. 264 draw the sun's true bearing (110°). The subsolar point cannot be shown, but the bearing line points toward it. Since the observed altitude is 1° greater than the calculated altitude at the assumed position, the plane must be on a position circle 60 miles nearer

the subsolar point than was previously assumed. Step off 60 miles from the assumed position toward the subsolar point (*i.e.*, along the true bearing line), and through the position thus established draw a small portion of the position circle XY. The plane is on this line of position.

NOTE: The difference between an observed and calculated altitude is termed the **intercept.** In the problem just given, the value of the intercept was 1°, or 60 miles. As soon as the intercept value has been obtained, it is customary to label it "toward" if, as in the problem above, it is to be stepped off *toward* the body. When the observed altitude is less than the calculated altitude, the intercept is stepped off *away* from the assumed position; in such cases the intercept is at once labeled "away."

2. Using the chart in Fig. 264 and the following data, show the plane's line of position:

Assumed position	17°N. 35°40′W.
Calculated true bearing	40°
Calculated altitude	61°30′
Time	$15^h21^m06^s$ GCT
Observed altitude	61°

3. Using the chart in Fig. 264 and the following data, show the plane's line of position:

Assumed position	19°N. 34°51′W.
Calculated true bearing	285°
Calculated altitude	28°17′
Time	$03^h41^m39^s$ GCT
Observed altitude	29°07′

4. Using the chart in Fig. 265[1] and the following data, show the plane's line of position:

Assumed position	28°S. 91°13′W.
Calculated true bearing	127°
Calculated altitude	43°09′
Time	$06^h03^m05^s$ GCT
Observed altitude	42°53′

5. Using the chart in Fig. 265[1] and the following data, show the plane's line of position:

Assumed position	27°S. 90°42′W.
Calculated true bearing	203°
Calculated altitude	18°49′
Time	$06^h06^m27^s$ GCT
Observed altitude	19°07′

The data required for the computation of a celestial body's true bearing and altitude at an assumed position are listed below:

1. Latitude of assumed position.
2. Declination of the observed body.
3. Local hour angle, or t, of the observed body.

[1] **Figure 265 is contained in the pocket in the back of the book.**

The student is already familiar with the first two of these values; the third requires an explanation.

LHA and *t*.—The GHA of a body is its westerly angle from the *Greenwich* meridian; the **local hour angle** (LHA) of a body is its westerly angle from the *navigator's* meridian of longitude.

If the GHA of a body is 100°, it is 100° west of the Greenwich meridian; but to an observer on the 60th west longitude meridian the body is only 40° to the westward. Therefore, at the observer's meridian the

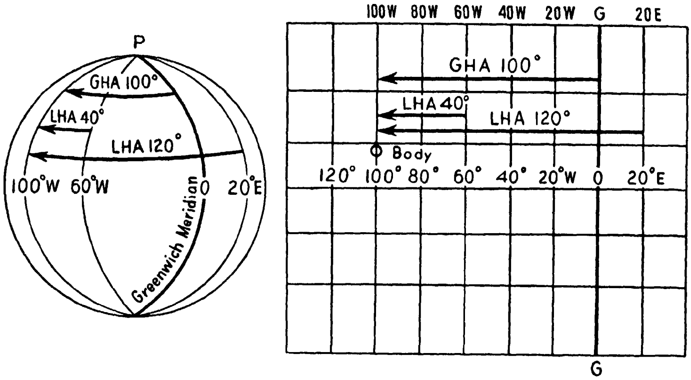


Fig. 266.—Determination of a body's LHA using GHA and longitude.

LHA is 40°. To an observer on the 20th east longitude meridian, the LHA at this time would be 120°. This is shown graphically in Fig. 266.

PROBLEMS

1. On Apr. 15, 1943, a navigator assumed his plane to be in 40°N. Lat. 20°14′E. Long. at $10^h15^m20^s$ GCT. What were the LHA and declination of the sun? Use Figs. 258 and 260 (pages 220 and 223). Diagram the answer.

Procedure	GHA of the sun at $10^h10^m00^s$ GCT	332°26′
	Corr. for 5^m20^s	1 20
	GHA of the sun at $10^h15^m20^s$ GCT	333 46
	Long. 20°14′E. (add)	20 14
	LHA	354 00
	Dec. 9°31′N.	

Note: The position of the plane used in this problem was an assumed position, and it was reasonably close to the actual position—insofar as this was known at the time of observation. For convenience in subsequent computations or use of navigation tables the latitude was chosen to the nearest whole degree. The assumed longitude was purposely chosen so as to result in a whole degree value of LHA. This is the procedure followed in the air and that followed in subsequent problems.

2. On Apr. 15, 1943, a navigator observed the altitude of the star Deneb at $02^h20^m57^s$ GCT and assumed his plane to be located at 30°N. Lat., 20°45′W. Long.

Tabulate the data required for the determination of the star's bearing and computed altitude.

Procedure:	GHA of Aries at $02^h20^m00^s$ GCT	237°23′
	Corr. for 00^m57^s	14
	GHA of Aries at $02^h20^m57^s$ GCT	237 37
	SHA of Deneb	50 08
	GHA of Deneb	287 45
	Long. 20°45′ W. (subtract)	20 45
	LHA of Deneb*	267 00
	Dec. 45°05′N.*	
	Lat. 30°N.*	

* Required data.

3. On Apr. 15, 1943, near 37°05′N. Lat., 41°08′W. Long. the altitude of the sun was observed at $12^h20^m45^s$ GCT.

Required: The LHA, declination, and assumed latitude to be used in determining the altitude and true bearing of the body at the assumed position.

NOTE: Add 360° to the GHA if necessary in order to solve the problem.

When the LHA of a body is 0°, it is directly over some point on the observer's meridian; when the LHA of a body has increased to 180°,

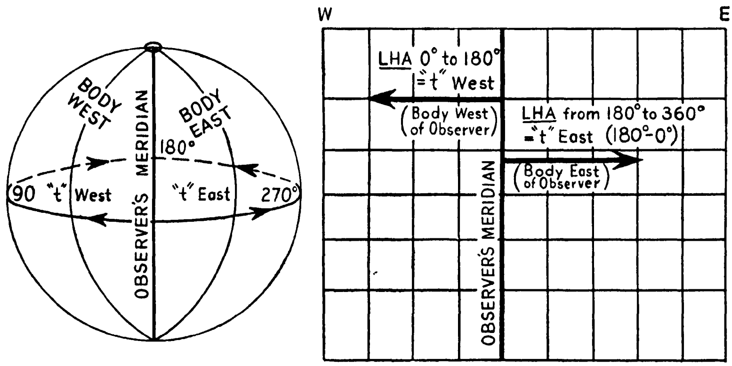


FIG. 267.—LHA vs. *t*.

it has moved 180° to the westward from the observer. Thereafter, as the celestial sphere continues to rotate, the body approaches the observer's meridian from the eastward.

If the LHA of a body is between 0 *and* 180°, *it is to the westward of the observer's meridian. When the LHA is between* 180 *and* 360° (0°), *the body is to the eastward* (see Fig. 267). These are very simple rules but extremely important. They must be thoroughly understood and memorized.

After the LHA has been determined, it is marked ***t*** **(meridian angle) west** when the body is no more than 180° west of the observer's meridian. When the body is to the eastward of the observer—as it would be if its

LHA were between 180 and 360°—its LHA is subtracted from 360° and the result is marked *t* (**meridian angle**) **east.** Thus the value of *t* never exceeds 180°, and the notation "west" or "east" placed beside it indicates whether the body bears to the westward or eastward from the observer's meridian. In some of the older texts and navigation tables the terms **LHA west** and **LHA east** are used with this same significance. In conformance with modern practice, the term LHA in this text indicates a westerly measurement of arc from 0 to 360°. The term ***t* east** or ***t* west** will designate meridian angles as described above.

PROBLEMS

1. The LHA of a body is 75°. In what other manner might this be expressed?
Ans.: t equals 75°W. or (in older texts) LHA 75°W.

2. The LHA of a body is 260°. In what other manner might this be expressed?
Ans.: t is 100°E. or (in older texts) LHA 100°E.

These two problems are shown graphically in Fig. 268.

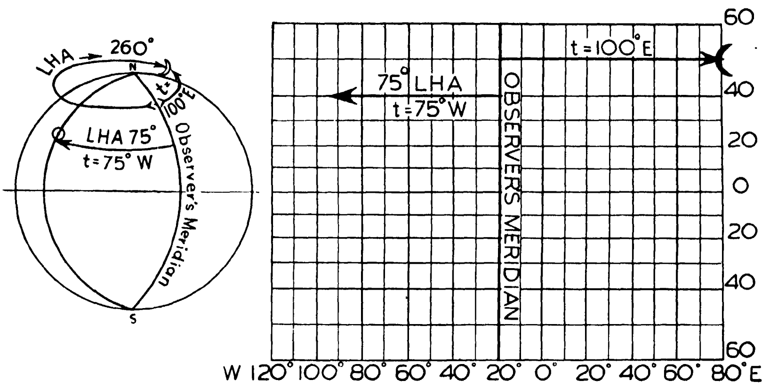


FIG. 268.—Graphic illustration of Prob. 1 and 2.

3. Supply the missing values in the following tabulation:

LHA	*t* Value	LHA east or west (used in old texts and tables)
316°		
	53°E.	
		71°W.
21		
	97 W.	
		107 E.
149		
	6 E.	
		1 W.
239		

True Bearings and Azimuths.—In Fig. 269 the value t at position A is 20°E.; from position B the value of t is 20°W. At both positions the same altitude is observed. Notice that the body C bears 35°east of north from position A and that it bears 35°west of north from position B (see the shaded areas).

Such angles are termed **azimuths.** They are important because the size of navigation tables is reduced by tabulating altitudes and azimuths rather than altitudes and true bearings. In this manner one tabulated set of values is made to serve for either an east or a west value of t. The navigator must change the tabulated azimuth to a true bearing

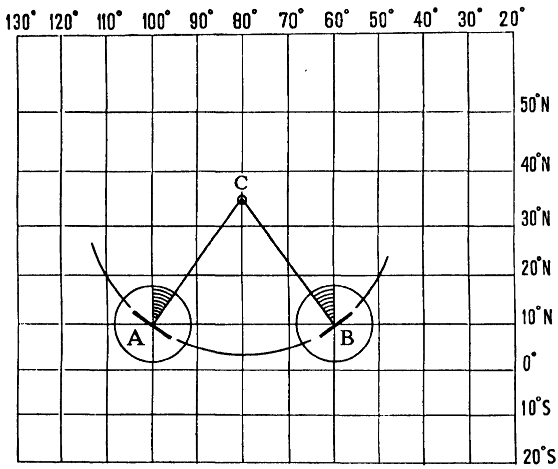


FIG. 269.—True bearings and azimuths.

when such change is indicated by the east-west notation he has placed beside t.

A portion of a modern navigation table that supplies values of computed altitude and azimuth when entered with values of latitude, declination, and t is shown in Fig. 270. Similar tables are used in flight and eliminate computation on the part of the navigator.

Tabulated azimuths are *always* angular measures from *true north* when the assumed position is in *north latitude.* Tabulated azimuths are *always* angular measures from *true south* when the assumed position is in *south latitude.*

PROBLEMS

1. From the data in the first three columns, determine the true bearing of the celestial body. Check your answers with those in column 4.

Lat. 39° 242

DECLINATION SAME NAME AS LATITUDE

"t" H.A.	12° 00′			12° 30′			13° 00′			13° 30′		
	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.
°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°
00	63 00.0	1.0 02	180.0	63 30.0	1.0 01	180.0	64 00.0	1.0 02	180.0	64 30.0	1.0 01	180.0
1	62 59.0	1.0 04	177.9	63 29.1	1.0 04	177.8	63 59.0	1.0 04	177.8	64 29.1	1.0 05	177.8
2	62 56.5	1.0 07	175.7	63 26.4	1.0 07	175.6	63 56.4	1.0 08	175.5	64 26.3	1.0 07	175.5
3	62 52.0	99 10	173.5	63 22.0	99 10	173.4	63 51.8	99 10	173.3	64 21.8	99 11	173.2
4	62 46.0	99 13	171.4	63 15.8	99 13	171.2	63 45.6	99 13	171.1	64 15.4	99 14	171.0
05	62 38.2	99 16	169.3	63 07.9	99 15	169.1	63 37.5	99 16	169.0	64 07.2	99 16	168.8
6	62 28.7	98 18	167.2	62 58.3	98 19	167.0	63 27.8	98 19	166.8	63 57.3	98 19	166.6
7	62 17.6	98 21	165.2	62 47.0	98 22	164.9	63 16.2	98 22	164.7	63 45.6	97 22	164.5
8	62 04.8	97 24	163.1	62 34.0	97 24	162.8	63 03.1	97 24	162.6	63 32.3	97 25	162.3
9	61 50.5	97 27	161.1	62 19.5	97 27	160.8	62 43.4	97 27	160.5	63 17.3	96 28	160.2
10	61 34.5	96 29	159.1	62 03.4	96 29	158.8	62 32.0	96 30	158.5	63 00.7	95 30	158.2
1	61 17.2	95 31	157.1	61 45.8	95 32	156.8	62 14.1	95 32	156.5	62 42.6	94 33	156.1
2	60 58.3	94 34	155.2	61 26.7	94 34	154.9	61 54.7	94 34	154.5	62 23.0	94 35	154.1
3	60 38.1	93 36	153.3	61 06.2	93 36	152.9	61 34.0	93 37	152.6	62 02.0	93 37	152.2
4	60 16.5	93 38	151.5	60 44.3	92 39	151.1	61 11.8	92 39	150.7	61 39.5	92 39	150.3
15	59 53.6	92 40	149.7	60 21.1	91 41	149.3	60 48.4	91 41	148.9	61 15.8	91 42	148.4
6	59 29.5	91 42	147.9	59 56.7	90 43	147.5	60 23.7	90 43	147.1	60 50.8	90 44	146.6
7	59 04.1	90 44	146.2	59 31.0	89 45	145.7	59 57.7	89 45	145.3	60 24.5	89 46	144.8
8	58 37.6	89 46	144.5	59 04.2	88 46	144.1	59 30.6	88 47	143.6	59 57.1	88 47	143.1
9	58 10.0	88 48	142.9	58 36.3	87 48	142.4	59 02.4	87 49	141.9	59 28.6	86 49	141.4

14° 00′			14° 30′			15° 00′			15° 30′			"t" H.A.
Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	
° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	°
65 00.0	1.0 02	180.0	65 30.0	1.0 01	180.0	66 00.0	1.0 02	180.0	66 30.0	1.0 02	180.0	00
64 59.0	1.0 04	177.7	65 29.1	1.0 05	177.7	65 58.9	1.0 04	177.6	66 29.0	1.0 05	177.6	1
64 56.3	1.0 08	175.4	65 26.2	1.0 08	175.3	65 56.2	1.0 08	175.2	66 26.1	99 08	175.2	2
64 51.6	99 11	173.1	65 21.5	99 11	173.0	65 51.3	99 11	172.9	66 21.2	99 11	172.8	3
64 45.1	99 14	170.8	65 14.9	99 14	170.7	65 44.6	99 14	170.5	66 14.4	99 15	170.4	4
64 36.8	99 17	168.6	65 06.4	99 17	168.4	65 36.0	99 17	168.2	66 05.6	99 18	168.0	05
64 26.7	98 20	166.4	64 56.2	98 20	166.2	65 25.7	98 20	166.0	65 55.0	98 21	165.7	6
64 14.9	97 23	164.2	64 44.2	97 23	164.0	65 13.4	97 23	163.7	65 42.6	97 24	163.4	7
64 01.3	97 25	162.0	64 30.4	97 26	161.7	64 59.4	97 26	161.5	65 28.4	96 28	161.2	8
63 46.1	96 28	159.9	64 15.0	96 28	159.6	64 43.7	96 29	159.3	65 12.5	95 29	158.9	9
63 29.2	95 30	157.8	63 57.9	95 31	157.5	64 26.4	95 31	157.1	64 54.9	95 32	156.7	10
63 10.9	94 33	155.8	63 39.3	94 34	155.4	64 07.5	94 34	155.0	64 35.7	94 34	154.6	1
62 51.0	94 35	153.8	63 19.1	93 36	153.4	63 47.0	93 36	153.0	64 15.0	93 37	152.6	2
62 29.7	93 38	151.8	62 57.5	92 38	151.3	63 25.1	92 39	150.9	63 52.7	92 39	150.5	3
62 07.0	92 40	149.8	62 34.5	91 41	149.4	63 01.8	91 41	149.0	63 29.1	90 42	148.5	4
61 42.9	91 42	148.0	62 10.1	90 43	147.5	62 37.1	90 43	147.1	63 04.1	89 44	146.6	15
61 17.6	90 44	146.2	61 44.4	89 45	145.7	62 11.1	89 45	145.2	62 37.8	88 46	144.7	6
60 51.0	89 46	144.4	61 17.6	88 47	143.9	61 43.9	88 47	143.4	62 10.2	87 48	142.9	7
60 23.2	88 48	142.6	60 49.5	87 49	142.1	61 15.5	87 49	141.6	61 41.5	86 50	141.1	8
59 54.4	86 50	140.9	60 20.3	86 50	140.4	60 46.0	86 51	139.9	61 11.7	85 51	139.4	9

FIG. 270.—Portion of a modern navigation table. (H.O.214).

Latitude	t	Azimuth	True bearing
35°N.	30°E.	117°	117°
20 S.	85 W.	20	200
53 S.	125 E.	39	141
19 N.	8 W.	157	203
46 S.	142 W.	39	219

2. From the following data, determine the true bearing of the celestial body:

Assumed lat.	t	Azimuth
21°N.	37°E.	61°
35 S.	83 W.	78
46 S.	51 E.	93
59 N.	78 E.	53
13 S.	3 E.	159

Azimuths tabulated for an assumed position on the *equator* are measured from *north* when the body's *declination is north* and from *south* when the body's *declination is south.* Whether this measurement is to the east or west always depends, as previously stated, on whether the notation placed beside t is "east" or "west."

Problem: From the following data, determine the true bearing of the celestial body (0°Lat.):

t	Dec.	Azimuth
East	North	80°
East	North	3
West	South	46
East	South	64
West	North	29
East	North	55
West	South	77
East	South	80
West	North	61
East	North	78

Use of Navigation Tables—Blackburn's.—In the problems thus far the calculated altitude has been supplied the student. While such computed altitudes may be obtained through the use of mathematical formulas, they are for the most part obtained from tables of precomputed altitudes and azimuths.

A page taken from one of the more recent navigation tables is reproduced in Fig. 271. This table is used in connection with star observa-

tions, and it eliminates all computations except that connected with the Air Almanac. The names of the principal navigational stars are printed in alphabetical order across the top of the sheet. The calculated altitude and azimuth for each star is given opposite the t value shown in the left-hand column. The sheet shown in the figure is used when the assumed latitude is 30°N.

The following problem is intended not only to illustrate the use of this table but also to crystallize the student's routine in dealing with assumed positions, Air Almanac data, azimuth, altitude, and t.

Problem: The observed altitude h_o of Rigel was 25°55′ at $19^h23^m47^s$ GCT, Apr. 15, 1943. At this time the plane was located at approximately 30°N. and 02°W.

Required: Determine the computed altitude h_c, true bearing, and intercept. Label the intercept "toward" or "away" depending on whether the observed altitude h_o is greater or less than the computed altitude h_c.

Procedure:	GHA of Aries at $19^h20^m00^s$ GCT	133°04′
	Corr. for 3^m47^s	57
	SHA of Rigel	282 03
	GHA of Rigel	416 04
	Assumed long.	02 04W.
	LHA of Rigel	414 00
	Assumed lat. 30°N.	
	t is 54°W.	

NOTE: The intermediate step of finding the GHA of Aries for $19^h23^m47^s$ was omitted. This is common practice in the air where every timesaving device is used.

Inspection of Fig. 271 shows that for 30°N. Lat. and t 54° the altitude and azimuth should be 25°35′ and 118°. These data are handled as shown below:

25°35h_c	Azimuth 117°N. and W.
25 55h_o	360
Intercept 20 toward	243° true bearing

NOTE: The student should learn to subtract upward as well as downward; it often saves time.

The line of position resulting from this observation is shown plotted in Fig. 272. Only the line of position is plotted on the chart, but the star's name and time of observation are customarily noted as shown.

PROBLEMS

1. The observed altitude of the star Sirius was 38°01′ at $18^h36^m08^s$ GCT, Apr. 15, 1943. At this time the plane was in the vicinity of 30°25′N. Lat., 01°50′E. Long.

30° N.

t	Aldebaran h_c	Aldebaran Az.	Alphard h_c	Alphard Az.	Alpheratz h_c	Alpheratz Az.	Altair h_c	Altair Az.	Antares h_c	Antares Az.
	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°
00	76 24	180	51 35	180	88 48	180	68 44	180	33 41	180
1	76 22	176	51 34	178	88 31	144	68 42	177	33 41	179
2	76 17	172	51 32	177	87 53	124	68 39	175	33 39	178
3	76 08	168	51 28	175	87 08	114	68 32	172	33 37	177
4	75 55	164	51 23	174	86 19	108	68 24	169	33 33	176
05	75 39	160	51 17	172	85 29	104	68 13	167	33 29	175
6	75 20	157	51 09	171	84 38	102	68 00	164	33 24	174
7	74 58	153	51 00	169	83 47	100	67 44	161	33 17	172
8	74 33	150	50 49	168	82 56	98	67 27	159	33 10	172
9	74 06	147	50 37	166	82 04	97	67 07	157	33 02	170
10	73 36	144	50 24	164	81 13	96	66 46	154	32 53	169
1	73 05	141	50 09	163	80 21	96	66 22	152	32 43	168
2	72 31	138	49 53	161	79 29	94	65 57	150	32 32	167
3	71 56	136	49 36	160	78 37	93	65 30	148	32 20	166
4	71 19	134	49 17	159	77 45	92	65 01	146	32 07	165
15	70 41	131	48 58	157	76 53	92	64 31	144	31 53	164
6	70 01	129	48 37	156	76 01	91	63 59	142	31 38	163
7	69 20	127	48 15	154	75 09	91	63 26	140	31 23	162
8	68 38	126	47 52	153	74 17	90	62 52	138	31 07	161
9	67 56	124	47 27	152	73 25	90	62 17	136	30 49	160
20	67 12	122	47 02	150	72 34	89	61 40	135	30 31	159
1	66 28	121	46 36	149	71 42	89	61 03	133	30 12	158
2	65 43	119	46 09	148	70 50	88	60 24	131	29 53	157
3	64 57	118	45 40	147	69 58	88	59 45	130	29 32	156
4	64 11	116	45 11	145	69 06	87	59 05	129	29 11	155
25	63 24	115	44 41	144	68 14	87	58 24	127	28 49	154
6	62 37	114	44 10	143	67 22	87	57 42	126	28 26	154
7	61 49	113	43 38	142	66 30	86	56 59	125	28 02	153
8	61 01	112	43 06	141	65 38	86	56 16	123	27 38	152
9	60 12	111	42 32	140	64 46	86	55 32	122	27 13	151
30	59 24	110	41 58	138	63 55	85	54 48	121	26 47	150
1	58 35	109	41 23	137	63 03	85	54 03	120	26 21	149
2	57 45	108	40 47	136	62 11	85	53 18	119	25 54	148
3	56 55	107	40 11	135	61 19	84	52 32	118	25 26	147
4	56 06	106	39 34	134	60 28	84	51 46	117	24 58	146
35	55 16	105	38 56	133	59 36	84	50 59	116	24 28	146
6	54 25	104	38 18	132	58 45	83	50 12	115	23 59	145
7	53 35	104	37 40	131	57 53	83	49 25	114	23 29	144
8	52 44	103	37 00	130	57 01	82	48 38	113	22 58	143
9	51 54	102	36 20	130	56 10	82	47 49	112	22 26	142
40	51 03	101	35 40	129	55 19	82	47 01	111	21 54	142
1	50 12	101	34 59	128	54 27	82	46 13	110	21 22	141
2	49 20	100	34 17	127	53 36	81	45 24	110	20 49	140
3	48 29	99	33 36	126	52 44	81	44 35	109	20 15	139
4	47 38	99	32 53	125	51 53	81	43 45	108	19 41	139

Arcturus h_c	Arcturus Az.	Betelgeux h_c	Betelgeux Az.	Capella h_c	Capella Az.	Deneb h_c	Deneb Az.	Deneb Kaitos h_c	Deneb Kaitos Az.	Denebola h_c	Denebola Az.	t
° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	
79 28	180	67 24	180	74 03	00	74 55	00	41 43	180	74 52	180	00
79 26	175	67 23	177	74 02	03	74 54	03	41 42	179	74 51	176	1
79 19	170	67 19	175	73 59	05	74 50	05	41 41	177	74 46	173	2
79 07	165	67 14	172	73 53	08	74 44	08	41 38	176	74 37	169	3
78 51	160	67 05	170	73 45	10	74 35	11	41 34	175	74 26	165	4
78 32	156	66 55	167	73 35	12	74 25	13	41 29	174	74 11	162	05
78 09	151	66 43	165	73 23	15	74 12	16	41 22	173	73 54	159	6
77 42	147	66 28	162	73 09	17	73 57	18	41 15	171	73 34	155	7
77 13	144	66 11	160	72 53	19	73 39	21	41 06	170	73 11	152	8
76 41	140	65 52	158	72 35	21	73 20	23	40 57	169	72 45	149	9
76 06	137	65 32	155	72 15	23	72 59	25	40 46	168	72 18	147	10
75 30	134	65 09	153	71 53	25	72 37	27	40 34	166	71 48	144	1
74 52	131	64 45	151	71 30	27	72 13	29	20 41	165	71 17	141	2
74 12	129	64 19	149	71 06	29	71 47	31	40 07	164	70 43	139	3
73 31	126	63 51	147	70 40	30	71 20	32	39 52	163	70 08	137	4
72 49	124	63 23	145	70 13	32	70 52	34	39 36	162	69 32	134	15
72 05	122	62 52	143	69 45	34	70 22	36	39 19	160	68 54	132	6
71 21	120	62 20	141	69 16	35	69 51	37	39 01	159	68 15	130	7
70 36	119	61 47	139	68 45	36	69 20	38	38 42	158	67 35	129	8
69 50	117	61 13	138	68 14	38	68 47	40	38 22	157	66 54	127	9
69 03	116	60 37	136	67 42	39	68 14	41	38 01	156	66 11	125	20
68 16	114	60 01	135	67 09	40	67 39	42	37 39	155	65 28	124	1
67 28	113	59 24	133	66 35	41	67 04	43	37 16	154	64 45	122	2
66 40	111	58 45	132	66 01	42	66 29	44	36 53	153	64 00	121	3
65 52	110	58 06	130	65 26	43	65 53	45	36 28	152	63 15	119	4
65 03	109	57 26	129	64 50	44	65 16	46	36 03	150	62 30	118	25
64 13	108	56 45	127	64 14	44	64 39	47	35 37	149	61 43	117	6
63 24	107	56 03	126	63 37	45	64 01	47	35 09	148	60 57	115	7
62 34	106	55 21	125	63 00	46	63 23	48	34 42	147	60 09	114	8
61 44	105	54 38	124	62 23	47	62 44	49	34 13	146	59 22	113	9
60 54	104	53 55	123	61 45	47	62 05	49	33 44	145	58 34	112	30
60 03	103	53 11	121	61 06	48	61 26	50	33 14	144	57 46	111	1
59 13	103	52 26	120	60 28	48	60 46	50	32 43	143	56 57	110	2
58 22	102	51 41	119	59 49	49	60 06	51	32 12	143	56 08	109	3
57 31	101	50 56	118	59 09	49	59 26	51	31 40	142	55 19	108	4
56 40	100	50 10	117	58 30	50	58 45	52	31 07	141	54 29	107	35
55 49	100	49 24	116	57 50	50	58 05	52	30 33	140	53 40	107	6
54 57	99	48 37	115	57 10	50	57 24	52	30 00	139	52 50	106	7
54 06	98	47 50	114	56 30	51	56 43	53	29 25	138	52 00	105	8
53 15	98	47 02	114	55 50	51	56 02	53	28 50	137	51 09	104	9
52 23	97	46 15	113	55 09	51	55 20	53	28 14	136	50 19	103	40
51 31	96	45 27	112	54 28	52	54 39	53	27 38	136	49 28	103	1
50 40	96	44 38	111	53 47	52	53 57	54	27 01	135	48 37	102	2
49 48	95	43 50	110	53 06	52	53 15	54	26 24	134	47 47	101	3
48 56	94	43 01	110	52 25	52	52 33	54	25 46	133	46 55	101	4

45	**46 46**	98	**32 11**	124	**51 02**	80	**42 56**	107	**19 06**	138	**48 04**	94	**42 12**	109	**51 44**	53	**51 51**	54	**25 08**	132	**46 04**	100	**45**
6	**45 55**	97	**31 27**	124	**50 11**	80	**42 06**	107	**18 31**	137	**47 12**	93	**41 22**	108	**51 03**	53	**51 09**	54	**24 29**	132	**45 13**	99	**6**
7	**45 03**	97	**30 44**	123	**49 20**	80	**41 16**	106	**17 56**	136	**46 21**	93	**40 33**	107	**50 21**	53	**50 27**	54	**23 50**	131	**44 22**	99	**7**
8	**44 12**	96	**30 00**	122	**48 29**	79	**40 26**	105	**17 20**	136	**45 29**	92	**39 43**	107	**49 40**	53	**49 45**	54	**23 10**	130	**43 30**	98	**8**
9	**43 20**	96	**29 16**	121	**47 38**	79	**39 36**	105	**16 43**	135	**44 37**	92	**38 53**	106	**48 58**	53	**49 03**	55	**22 30**	129	**42 39**	97	**9**
50	**42 28**	95	**28 31**	121	**46 47**	79	**38 46**	104	**16 06**	134	**43 45**	91	**38 03**	105	**48 17**	53	**48 21**	55	**21 49**	129	**41 47**	97	**50**
1	**41 37**	94	**27 46**	120	**45 56**	78	**37 55**	103	**15 29**	134	**42 53**	91	**37 13**	104	**47 35**	53	**47 38**	55	**21 08**	128	**40 56**	96	**1**
2	**40 45**	94	**27 01**	119	**45 05**	78	**37 05**	103	**14 51**	133	**42 01**	90	**36 23**	104	**46 54**	53	**46 56**	55	**20 27**	127	**40 04**	96	**2**
3	**39 53**	93	**26 15**	118	**44 14**	78	**36 14**	102	**14 13**	132	**41 09**	90	**35 32**	103	**46 12**	53	**46 14**	55	**19 45**	127	**39 12**	95	**3**
4	**39 01**	93	**25 29**	118	**43 23**	77	**35 23**	101	**13 34**	132	**40 17**	89	**34 42**	103	**45 30**	53	**45 31**	55	**19 03**	126	**38 20**	95	**4**
55	**38 09**	92	**24 43**	117	**42 33**	77	**34 32**	101	**12 55**	131	**39 25**	89	**33 51**	102	**44 49**	53	**44 49**	55	**18 21**	125	**37 29**	94	**55**
6	**37 17**	92	**23 57**	116	**41 42**	77	**33 41**	100	**12 16**	131	**38 33**	88	**33 00**	101	**44 07**	53	**44 07**	55	**17 38**	125	**36 37**	93	**6**
7	**36 25**	91	**23 10**	116	**40 52**	76	**32 49**	100	**11 36**	130	**37 41**	88	**32 09**	101	**43 25**	53	**43 24**	55	**16 55**	124	**35 45**	93	**7**
8	**35 33**	91	**22 23**	115	**40 01**	76	**31 58**	99	**10 56**	129	**36 49**	87	**31 18**	100	**42 43**	53	**42 42**	55	**16 12**	123	**34 53**	92	**8**
9	**34 41**	90	**21 36**	114	**39 11**	76	**31 07**	98	**10 16**	129	**35 57**	87	**30 27**	100	**42 02**	53	**42 00**	55	**15 28**	123	**34 01**	92	**9**
60	**33 49**	90	**20 48**	114	**38 20**	75	**30 15**	98	**9 35**	128	**35 05**	86	**29 35**	99	**41 20**	53	**41 17**	55	**14 44**	122	**33 09**	91	**60**
1	**32 57**	89	**20 00**	113	**37 30**	75	**29 24**	97	**8 54**	127	**34 14**	86	**28 44**	98	**40 38**	53	**40 35**	55	**14 00**	121	**32 17**	91	**1**
2	**32 05**	89	**19 12**	112	**36 40**	75	**28 32**	97	**8 13**	127	**33 22**	85	**27 53**	98	**39 57**	53	**39 53**	54	**13 15**	121	**31 25**	90	**2**
3	**31 13**	88	**18 24**	112	**35 50**	74	**27 41**	96	**7 31**	126	**32 30**	85	**27 01**	97	**39 15**	53	**39 10**	54	**12 30**	120	**30 33**	90	**3**
4	**30 21**	88	**17 36**	111	**35 00**	74	**26 49**	96	**6 49**	126	**31 38**	85	**26 10**	97	**38 34**	53	**38 28**	54	**11 45**	120	**29 41**	89	**4**
65	**29 30**	87	**16 47**	111	**34 10**	74	**25 57**	95	**6 07**	125	**30 47**	84	**25 18**	96	**37 52**	53	**37 46**	54	**11 00**	119	**28 49**	89	**65**
6	**28 38**	87	**15 58**	110	**33 20**	73	**25 05**	94	**5 24**	125	**29 55**	84	**24 26**	96	**37 11**	53	**37 04**	54	**10 14**	118	**27 57**	88	**6**
7	**27 46**	86	**15 09**	109	**32 30**	73	**24 14**	94			**29 03**	83	**23 35**	95	**36 29**	53	**36 22**	54	**9 28**	118	**27 06**	88	**7**
8	**26 54**	86	**14 20**	109	**31 41**	73	**23 22**	93			**28 12**	83	**22 43**	95	**35 48**	53	**35 40**	54	**8 42**	117	**26 14**	87	**8**
9	**26 02**	85	**13 31**	108	**30 51**	72	**22 30**	93			**27 20**	82	**21 51**	94	**35 07**	52	**34 58**	54	**7 55**	117	**25 22**	87	**9**
70	**25 10**	85	**12 42**	108	**30 02**	72	**21 38**	92			**26 29**	82	**20 59**	93	**34 25**	52	**34 17**	54	**7 09**	116	**24 30**	86	**70**
1	**24 19**	84	**11 52**	107	**29 12**	72	**20 46**	92			**25 37**	81	**20 07**	93	**33 44**	52	**33 35**	53	**6 22**	116	**23 38**	86	**1**
2	**23 27**	84	**11 02**	107	**28 33**	71	**19 54**	91			**24 46**	81	**19 15**	92	**33 03**	52	**32 53**	53	**5 35**	115	**22 46**	85	**2**
3	**22 35**	84	**10 13**	106	**27 34**	71	**19 02**	91			**23 55**	81	**18 23**	92	**32 22**	52	**32 12**	53			**21 54**	85	**3**
4	**21 44**	83	**9 23**	106	**26 45**	71	**18 10**	90			**23 04**	80	**17 31**	91	**31 41**	52	**31 31**	53			**21 03**	85	**4**
75	**20 52**	83	**8 32**	105	**25 56**	70	**17 18**	90			**22 12**	80	**16 40**	91	**31 01**	52	**30 49**	53			**20 11**	84	**75**
6	**20 01**	82	**7 42**	105	**25 07**	70	**16 26**	89			**21 21**	79	**15 48**	90	**30 20**	51	**30 08**	52			**19 19**	84	**6**
7	**19 09**	82	**6 52**	104	**24 18**	70	**15 34**	89			**20 30**	79	**14 56**	90	**29 39**	51	**29 27**	52			**18 28**	83	**7**
8	**18 18**	81	**6 01**	103	**23 29**	69	**14 42**	88			**19 39**	78	**14 04**	89	**28 59**	51	**28 46**	52			**17 36**	83	**8**
9	**17 26**	81	**5 11**	103	**22 41**	69	**13 50**	88			**18 49**	78	**13 12**	89	**28 19**	51	**28 05**	52			**16 45**	82	**9**
80	**16 35**	80			**21 53**	68	**12 58**	87			**17 58**	78	**12 20**	88	**27 38**	51	**27 24**	52			**15 53**	82	**80**
1	**15 44**	80			**21 04**	68	**12 07**	87			**17 07**	77	**11 28**	88	**26 58**	50	**26 44**	51			**15 02**	81	**1**
2	**14 53**	79			**20 16**	68	**11 15**	86			**16 17**	77	**10 36**	87	**26 18**	50	**26 03**	51			**14 10**	81	**2**
3	**14 02**	79			**19 28**	67	**10 23**	86			**15 26**	76	**9 44**	87	**25 38**	50	**25 23**	51			**13 19**	80	**3**
4	**13 11**	78			**18 40**	67	**9 31**	85			**14 36**	76	**8 52**	86	**24 59**	50	**24 43**	51			**12 28**	80	**4**
85	**12 20**	78			**17 53**	67	**8 39**	85			**13 45**	75	**8 00**	86	**24 19**	49	**24 03**	50			**11 37**	79	**85**
6	**11 29**	78			**17 05**	66	**7 47**	84			**12 55**	75	**7 08**	85	**23 40**	49	**23 23**	50			**10 46**	79	**6**
7	**10 39**	77			**16 18**	66	**6 56**	84			**12 05**	74	**6 17**	85	**23 01**	49	**22 43**	50			**9 55**	79	**7**
8	**9 48**	77			**15 30**	65	**6 04**	83			**11 15**	74	**5 25**	84	**22 21**	49	**22 03**	50			**9 04**	78	**8**
9	**8 57**	76			**14 43**	65	**5 13**	83			**10 25**	73			**21 42**	48	**21 24**	49			**8 13**	77	**9**
90	**8 07**	76			**13 56**	65	**4 21**	82			**9 35**	73			**21 04**	48	**20 44**	49			**7 22**	77	**90**

FIG. 271.

30° N.

t	Dubhe h_c	Dubhe Az.	Fomalhaut h_c	Fomalhaut Az.	Markab h_c	Markab Az.	Pollux h_c	Pollux Az.	Procyon h_c	Procyon Az.	Rasalague h_c	Rasalague Az.	Regulus h_c	Regulus Az.	Rigel h_c	Rigel Az.	Sirius h_c	Sirius Az.	Spica h_c	Spica Az.	Vega h_c	Vega Az.	t
	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	° ′	°	
00	57 57	00	30 06	180	74 55	180	88 10	180	65 22	180	72 36	180	72 14	180	51 44	180	43 22	180	49 07	180	81 16	00	00
1	57 57	01	30 05	179	74 53	176	87 58	154	65 21	178	72 34	177	72 12	177	51 44	178	43 21	179	49 07	179	81 14	05	1
2	57 56	02	30 04	178	74 48	173	87 28	136	65 18	175	72 30	174	72 08	174	51 41	177	43 19	177	49 05	177	81 07	10	2
3	57 54	03	30 01	177	74 40	169	86 48	124	65 12	173	72 22	170	72 01	171	51 38	175	43 16	176	49 01	176	80 56	15	3
4	57 51	04	29 58	176	74 28	165	86 03	117	65 05	171	72 13	167	71 51	167	51 33	174	43 12	175	48 56	174	80 40	20	4
05	57 47	04	29 54	175	74 14	162	85 16	112	64 55	168	72 00	164	71 38	164	51 26	172	43 07	173	48 50	173	80 21	24	05
6	57 43	05	29 49	174	73 56	159	84 27	108	64 43	166	71 44	161	71 23	161	51 18	171	43 00	172	48 43	171	79 58	28	6
7	57 38	06	29 43	173	73 36	155	83 37	105	64 30	164	71 26	158	71 05	158	51 09	169	42 53	171	48 34	169	79 32	32	7
8	57 32	07	29 37	172	73 13	152	82 46	103	64 14	161	71 05	155	70 45	156	50 58	167	42 44	170	48 24	168	79 04	35	8
9	57 25	08	29 29	171	72 48	149	81 56	101	63 57	159	70 42	153	70 22	153	50 47	166	42 34	168	48 13	167	78 33	38	9
10	57 18	09	29 20	170	72 20	147	81 04	99	63 37	157	70 17	150	69 58	150	50 33	164	42 23	167	48 00	165	78 00	41	10
1	57 10	10	29 11	169	71 50	144	80 13	98	63 16	155	69 50	147	69 31	148	50 18	163	42 10	166	47 46	164	77 25	43	1
2	57 01	10	29 01	168	71 19	141	79 22	97	62 53	153	69 21	145	69 02	145	50 02	161	41 57	165	47 31	162	76 49	45	2
3	56 51	11	28 50	167	70 45	139	78 30	96	62 29	151	68 50	143	68 32	143	49 45	160	41 42	163	47 15	161	76 12	47	3
4	56 41	12	28 38	166	70 10	137	77 38	95	62 03	149	68 18	140	68 00	141	49 27	158	41 27	162	46 57	160	75 33	49	4
15	56 30	13	28 25	165	69 34	134	76 46	94	61 36	147	67 44	138	67 26	139	49 07	157	41 10	161	46 39	158	74 53	51	15
6	56 18	14	28 11	164	68 56	132	75 55	94	61 07	145	67 09	136	66 51	137	48 46	156	40 53	160	46 19	157	74 12	52	6
7	56 05	14	27 57	163	68 17	130	75 03	93	60 37	144	66 32	134	66 15	135	48 24	154	40 34	158	45 58	156	73 31	54	7
8	55 52	15	27 41	162	67 36	129	74 11	92	60 05	142	65 54	132	65 38	133	48 01	152	40 14	157	45 36	154	72 49	55	8
9	55 39	16	27 25	162	66 55	127	73 19	91	59 33	140	65 15	131	64 59	131	47 36	151	39 54	156	45 13	153	72 06	56	9
20	55 24	17	27 08	161	66 13	125	72 27	91	58 59	139	64 35	129	64 19	130	47 11	150	39 32	155	44 49	152	71 23	57	20
1	55 09	17	26 51	160	65 30	124	71 35	91	58 24	137	63 55	127	63 39	128	46 45	149	39 10	154	44 24	150	70 39	58	1
2	54 54	18	26 32	159	64 46	122	70 43	90	57 48	136	63 13	126	62 57	126	46 17	148	38 46	153	43 58	149	69 55	58	2
3	54 38	19	26 13	158	64 02	121	69 51	90	57 11	134	62 30	124	62 15	125	45 49	146	38 22	152	43 31	148	69 11	59	3
4	54 21	19	25 53	157	63 17	119	68 59	89	56 34	133	61 47	123	61 32	123	45 20	145	37 56	150	43 03	147	68 26	60	4
25	54 04	20	25 32	156	62 31	118	68 07	89	55 55	131	61 03	122	60 49	122	44 49	144	37 30	149	42 34	146	67 41	60	25
6	53 46	20	25 11	155	61 45	117	67 15	88	55 16	130	60 18	120	60 04	121	44 18	143	37 03	148	42 04	144	66 56	61	6
7	53 27	21	24 49	154	60 58	115	66 23	88	54 35	129	59 33	119	59 19	120	43 46	142	36 36	147	41 34	143	66 11	61	7
8	53 09	22	24 26	153	60 11	114	65 31	87	53 54	127	58 48	118	58 34	118	43 14	140	36 07	146	41 02	142	65 25	62	8
9	52 49	22	24 02	153	59 23	113	64 39	87	53 13	126	58 01	117	57 48	117	42 40	139	35 38	145	40 30	141	64 39	62	9
30	52 30	23	23 38	152	58 35	112	63 47	87	52 31	125	57 15	116	57 02	116	42 06	138	35 08	144	39 57	140	63 53	62	30
1	52 09	23	23 13	151	57 47	111	62 56	86	51 48	124	56 28	115	56 15	115	41 31	137	34 37	143	39 24	139	63 07	63	1
2	51 49	24	22 47	150	56 58	110	62 04	86	51 05	123	55 40	114	55 27	114	40 55	136	34 05	142	38 49	138	62 21	63	2
3	51 28	24	22 21	149	56 09	109	61 12	85	50 21	122	54 52	113	54 40	113	40 19	135	33 33	141	38 14	137	61 34	63	3
4	51 06	25	21 54	149	55 20	108	60 20	85	49 36	121	54 04	112	53 52	112	39 42	135	33 00	140	37 38	136	60 48	63	4
35	50 44	25	21 27	148	54 31	107	59 28	85	48 51	120	53 16	111	53 03	111	39 04	133	32 27	139	37 02	135	60 02	64	35
6	50 22	26	20 59	147	53 41	107	58 37	84	48 06	119	52 27	110	52 15	110	38 26	132	31 53	139	36 25	134	59 15	64	6
7	49 59	26	20 30	146	52 51	106	57 45	84	47 20	118	51 38	109	51 26	109	37 47	131	31 18	138	35 48	133	58 28	64	7
8	49 36	27	20 01	145	52 01	105	56 53	84	46 34	117	50 49	108	50 37	108	37 07	130	30 43	137	35 09	132	57 42	64	8
9	49 13	27	19 31	145	51 11	104	56 02	83	45 48	116	49 59	107	49 47	108	36 27	129	30 07	136	34 31	131	56 55	64	9
40	48 49	27	19 01	144	50 20	103	55 10	83	45 01	115	49 09	106	48 58	107	35 47	128	29 30	135	33 51	130	56 08	64	40
1	48 25	28	18 30	143	49 29	103	54 19	82	44 14	114	48 20	106	48 08	106	35 06	127	28 53	134	33 12	130	55 21	64	1
2	48 01	28	17 58	143	48 39	102	53 27	82	43 26	113	47 29	105	47 18	105	34 24	127	28 16	133	32 31	129	54 35	64	2
3	47 37	28	17 26	142	47 48	101	52 36	82	42 38	113	46 39	104	46 28	105	33 42	126	27 37	133	31 51	128	53 48	64	3
4	47 12	29	16 54	141	46 57	101	51 44	82	41 50	112	45 49	103	45 37	104	33 00	125	26 59	132	31 09	127	53 01	64	4

45	**46 47**	29	**16 21**	140	**46 05**	100	**50 53**	81	**41 02**	111	**44 58**	103	**44 47**	103	**32 17**	124	**26 20**	131	**30 28**	126	**52 14**	64	**45**
6	**46 22**	29	**15 48**	140	**45 14**	99	**50 02**	81	**40 13**	110	**44 07**	102	**43 56**	103	**31 34**	123	**25 40**	130	**29 46**	125	**51 27**	64	**6**
7	**45 56**	30	**15 14**	139	**44 23**	99	**49 10**	81	**39 24**	110	**43 16**	101	**43 06**	102	**30 51**	123	**25 00**	129	**29 03**	125	**50 40**	64	**7**
8	**45 30**	30	**14 39**	138	**43 31**	98	**48 19**	80	**38 35**	109	**42 25**	101	**42 15**	101	**30 07**	122	**24 20**	129	**28 20**	124	**49 54**	64	**8**
9	**45 04**	30	**14 05**	138	**42 40**	97	**47 28**	80	**37 46**	108	**41 34**	100	**41 23**	101	**29 22**	121	**23 39**	128	**27 37**	123	**49 07**	64	**9**
50	**44 38**	30	**13 29**	137	**41 48**	97	**46 37**	79	**36 56**	107	**40 43**	99	**40 32**	100	**28 37**	120	**22 58**	127	**26 53**	122	**48 20**	64	**50**
1	**44 12**	31	**12 54**	136	**40 57**	96	**45 46**	79	**36 07**	107	**39 52**	99	**39 41**	99	**27 52**	120	**22 16**	127	**26 10**	122	**47 34**	64	**1**
2	**43 45**	31	**12 17**	136	**40 05**	96	**44 55**	79	**35 17**	106	**39 00**	98	**38 50**	99	**27 07**	119	**21 34**	126	**25 25**	121	**46 47**	64	**2**
3	**43 19**	31	**11 41**	135	**39 13**	95	**44 04**	78	**34 27**	105	**38 09**	98	**37 58**	98	**26 21**	118	**20 52**	125	**24 40**	120	**46 00**	64	**3**
4	**42 52**	31	**11 04**	134	**38 22**	95	**43 13**	78	**33 37**	105	**37 17**	97	**37 07**	97	**25 35**	117	**20 09**	124	**23 55**	120	**45 14**	64	**4**
55	**42 25**	31	**10 27**	134	**37 30**	94	**42 22**	78	**32 46**	104	**36 26**	97	**36 15**	97	**24 49**	117	**19 26**	124	**23 10**	119	**44 27**	63	**55**
6	**41 58**	32	**9 49**	133	**36 38**	93	**41 31**	78	**31 56**	103	**35 34**	96	**35 24**	96	**24 03**	116	**18 43**	123	**22 24**	118	**43 41**	63	**6**
7	**41 31**	32	**9 11**	133	**35 46**	93	**40 41**	77	**31 05**	103	**34 42**	96	**34 32**	96	**23 16**	115	**17 59**	122	**21 39**	118	**42 54**	63	**7**
8	**41 03**	32	**8 32**	132	**34 54**	92	**39 50**	77	**30 15**	102	**33 51**	95	**33 40**	95	**22 29**	115	**17 15**	122	**20 52**	117	**42 08**	63	**8**
9	**40 36**	32	**7 54**	132	**34 02**	92	**38 59**	77	**29 24**	102	**32 59**	94	**32 49**	95	**21 41**	114	**16 31**	121	**20 06**	116	**41 22**	63	**9**
60	**40 08**	32	**7 14**	131	**33 10**	91	**38 09**	76	**28 33**	101	**32 07**	94	**31 57**	94	**20 54**	113	**15 46**	121	**19 19**	116	**40 35**	63	**60**
1	**39 41**	32	**6 35**	130	**32 18**	91	**37 19**	76	**27 42**	100	**31 15**	93	**31 05**	94	**20 06**	113	**15 01**	120	**18 32**	115	**39 49**	63	**1**
2	**39 13**	32	**5 55**	130	**31 26**	90	**36 28**	75	**26 51**	100	**30 23**	93	**30 13**	93	**19 18**	112	**14 16**	119	**17 45**	114	**39 03**	62	**2**
3	**38 45**	32	**5 15**	129	**30 34**	90	**35 38**	75	**25 59**	99	**29 31**	92	**29 21**	93	**18 30**	112	**13 30**	119	**16 58**	114	**38 17**	62	**3**
4	**38 17**	33			**29 42**	89	**34 48**	75	**25 08**	99	**28 39**	92	**28 29**	92	**17 41**	111	**12 45**	118	**16 10**	113	**37 31**	62	**4**
65	**37 49**	33			**28 50**	89	**33 58**	75	**24 17**	98	**27 47**	91	**27 37**	91	**16 53**	110	**11 59**	118	**15 22**	113	**36 45**	62	**65**
6	**37 21**	33			**27 58**	88	**33 08**	74	**23 25**	98	**26 56**	91	**26 45**	91	**16 04**	110	**11 12**	117	**14 34**	112	**35 59**	62	**6**
7	**36 53**	33			**27 07**	88	**32 18**	74	**22 34**	97	**26 03**	90	**25 53**	90	**15 15**	109	**10 26**	116	**13 46**	111	**35 14**	61	**7**
8	**36 25**	33			**26 15**	87	**31 28**	74	**21 42**	97	**25 12**	90	**25 01**	90	**14 26**	109	**9 39**	116	**12 57**	110	**34 28**	61	**8**
9	**35 57**	33			**25 23**	87	**30 38**	73	**20 50**	96	**24 20**	89	**24 09**	89	**13 37**	108	**8 52**	115	**12 09**	110	**33 42**	61	**9**
70	**35 29**	33			**24 31**	86	**29 48**	73	**19 59**	96	**23 28**	89	**23 17**	89	**12 47**	108	**8 05**	115	**11 20**	110	**32 57**	61	**70**
1	**35 01**	33			**23 39**	86	**28 59**	72	**19 07**	95	**22 36**	88	**22 26**	88	**11 58**	107	**7 18**	114	**10 31**	109	**32 12**	61	**1**
2	**34 33**	33			**22 47**	85	**28 09**	72	**18 15**	94	**21 44**	88	**21 34**	88	**11 08**	106	**6 30**	114	**9 42**	109	**31 26**	60	**2**
3	**34 05**	33			**21 55**	85	**27 20**	71	**17 23**	94	**20 52**	87	**20 42**	87	**10 18**	106	**5 42**	113	**8 53**	108	**30 41**	60	**3**
4	**33 37**	33			**21 04**	85	**26 31**	71	**16 32**	93	**20 00**	87	**19 50**	87	**9 28**	105			**8 03**	107	**29 56**	60	**4**
75	**33 09**	33			**20 12**	84	**25 42**	71	**15 40**	93	**19 08**	86	**18 58**	87	**8 38**	105			**7 13**	107	**29 11**	60	**75**
6	**32 41**	33			**19 20**	84	**24 53**	71	**14 48**	92	**18 16**	86	**18 06**	86	**7 47**	104			**6 24**	106	**28 25**	59	**6**
7	**32 12**	33			**18 29**	83	**24 04**	70	**13 56**	92	**17 25**	85	**17 14**	86	**6 57**	104			**5 34**	106	**27 42**	59	**7**
8	**31 44**	33			**17 37**	83	**23 15**	70	**13 04**	91	**16 33**	85	**16 22**	85	**6 06**	103					**26 57**	59	**8**
9	**31 16**	33			**16 46**	82	**22 26**	70	**12 12**	91	**15 41**	84	**15 31**	85	**5 16**	103					**26 13**	59	**9**
80	**30 48**	33			**15 54**	82	**21 38**	69	**11 20**	90	**14 49**	84	**14 39**	84							**25 29**	58	**80**
1	**30 21**	33			**15 03**	81	**20 49**	69	**10 28**	90	**13 58**	83	**13 47**	84							**24 44**	58	**1**
2	**29 53**	33			**14 11**	81	**20 01**	68	**9 36**	89	**13 06**	83	**12 56**	83							**24 00**	58	**2**
3	**29 25**	32			**13 20**	80	**19 13**	68	**8 44**	89	**12 15**	82	**12 04**	83							**23 17**	57	**3**
4	**28 57**	32			**12 29**	80	**18 24**	68	**7 52**	88	**11 23**	82	**11 13**	82							**22 33**	57	**4**
85	**28 30**	32			**11 38**	79	**17 37**	67	**7 00**	88	**10 32**	81	**10 21**	82							**21 49**	57	**85**
6	**28 02**	32			**10 47**	79	**16 49**	67	**6 08**	87	**9 40**	81	**9 30**	81							**21 06**	56	**6**
7	**27 35**	32			**9 56**	79	**16 01**	66	**5 16**	87	**8 49**	80	**8 39**	81							**20 23**	56	**7**
8	**27 07**	32			**9 05**	78	**15 14**	66			**7 58**	80	**7 47**	80							**19 39**	56	**8**
9	**26 40**	32			**8 14**	77	**14 26**	66			**7 07**	80	**6 56**	80							**18 57**	55	**9**
90	**26 13**	32			**7 24**	77	**13 39**	65			**6 16**	79	**6 05**	79							**18 14**	55	**90**

FIG. 271.—(*Continued*)

Required: Determine the computed altitude h_c, true bearing, and intercept.

Procedure:	GHA of Aries at $18^h30^m00^s$	120°32′
	Corr. for 6^m08^s	1 32
	SHA of Sirius	259 20
	GHA of Sirius	381 24
	Assumed long.	01 36E.
	LHA of Sirius	383 00
	Assumed lat. 30°N.	
	t is 23°W.	

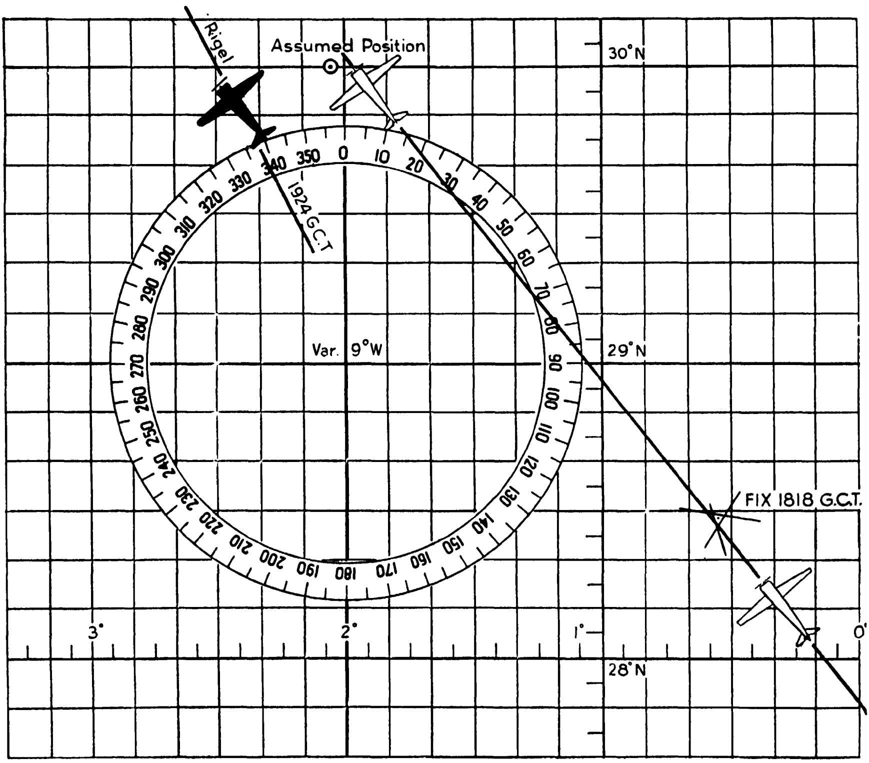


FIG. 272.—Plotting a celestial line of position.

Inspection of Fig. 271 furnishes the following data: 38°22′h_c and azimuth 151°.

38°22′h_c	152°N. and W. azimuth
38 01h_0	360
Intercept 21 away	208° true bearing

2. On Apr. 15, 1943, the observed altitude of Dubhe was 56°44′ at $20^h29^m19^s$ GCT. At this time the plane's approximate position was 29°32′N., 03°50′W. Solve for true bearing and intercept.

Ans: Intercept 52 toward. True bearing 15°.

3. On Apr. 15, 1943, the observed altitude of Deneb Kait. was 06°21′ at $06^h22^m42^s$ GCT. At this time the plane's approximate position was 30°15′N., 01°30′E. Solve for true bearing and intercept.

4. On Apr. 15, 1943, the observed altitude of Aldebaran was 25°49′ at $05^h30^m03^s$ GCT. At this time the plane's approximate position was 30°28′N. Lat., 148°51′W. Long. Solve for true bearing and intercept.

Use of Navigation Tables—H.O. 214.—A tabulation of h_c and azimuth for stars such as that of Fig. 271 is based on star declinations that remain practically constant. Declinations of other celestial bodies change from day to day and from hour to hour; because of this, it is impractical to tabulate h_c and azimuth for every conceivable declination value.

A typical page of one of the seven volumes of H.O. 214 is reproduced in Fig. 273. This table is widely used among air navigators, for it supplies a simple uniform means of obtaining h_c and azimuth for any body regardless of its declination. The h_c and azimuth values shown under columns 8°, 8°30′, 9°, etc., hold good as shown for all celestial bodies provided (1) that their declinations are exactly 8°, 8°30′, 9°, etc.; (2) that both declination and assumed latitude are of the same name, *i.e.*, both north or both south; and (3) that 35° is the assumed latitude.

In Fig. 274 the opposite page in H.O. 214 is reproduced. The values in these columns hold good for all bodies provided that the declination and assumed latitude are of contrary names, *i.e.*, one north and one south.

If the h_c is required for a body whose declination is 8°15′ instead of 8° or 8°30′, the value midway between the two tabulated values may be used. When such interpolation becomes necessary, the work can be simplified by multiplying the figure in the delta d column by the odd minutes of extra declination. The product thus obtained may then be applied to the h_c values shown in the table. In every case where this is done, the adjacent h_c column must be examined so as to determine whether the correction should be added to or subtracted from the tabulated value.

NOTE: The student is to bear in mind that HA as used in this table may designate either an easterly or a westerly measurement of arc. This is a case in point in which hour angle is used with precisely the same significance as was t in Blackburn's tables. The delta t column need not be used unless the navigator chooses to work with fractional rather than whole degree values of t.

Example: The LHA of the sun is 330°; the declination is 9°30′N., and the assumed latitude is 35°N.

Required: Determine the true bearing and h_c of the sun.

Procedure: The LHA equals 330; therefore, t or HA equals 30°E. Figure 273 supplies the following values: 52°35.6′h_c and azimuth 125.8. In this

Lat. 35°

DECLINATION SAME NAME AS LATITUDE

H.A.	8° 00′			8° 30′			9° 00′			9° 30′			10° 00′			10° 30′			11° 00′			11° 30′			H.A.
	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	Alt.		Az.	
°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	°
00	63 00.0	1.0 02	180.0	63 30.0	1.0 02	180.0	64 00.0	1.0 02	180.0	64 30.0	1.0 02	180.0	65 00.0	1.0 02	180.0	65 30.0	1.0 02	180.0	66 00.0	1.0 02	180.0	66 30.0	1.0 02	180.0	00
1	62 59.0	1.0 04	177.8	63 29.0	1.0 05	177.7	63 59.0	1.0 05	177.7	64 29.0	1.0 05	177.7	64 59.1	1.0 05	177.7	65 29.0	1.0 05	177.6	65 59.0	1.0 05	177.6	66 28.9	1.0 05	177.5	1
2	62 56.3	1.0 08	175.7	63 26.2	1.0 06	175.6	63 56.2	1.0 08	175.5	64 26.1	1.0 08	175.4	64 56.1	1.0 08	175.4	65 25.9	1.0 08	175.3	65 56.0	1.0 09	175.2	66 25.8	99 09	175.1	2
3	62 51.5	99 11	173.5	63 21.5	99 11	173.4	63 51.4	99 11	173.3	64 21.2	99 11	173.2	64 51.1	99 12	173.1	65 20.9	99 12	173.0	65 50.8	99 12	172.8	66 20.5	99 12	172.6	3
4	62 45.0	99 14	171.3	63 14.9	99 14	171.1	63 44.6	99 14	171.0	64 14.4	99 15	170.9	64 44.1	99 15	170.7	65 13.8	99 15	170.6	65 43.7	99 15	170.4	66 13.2	99 15	170.3	4
05	62 36.7	99 17	169.2	63 06.4	99 17	169.0	63 36.0	99 17	168.8	64 05.6	99 18	168.6	64 35.3	99 18	168.5	65 04.8	99 18	168.3	65 34.4	99 18	168.1	66 03.9	98 19	167.9	05
6	62 26.6	98 20	167.0	62 56.1	98 20	166.8	63 25.6	99 20	166.6	63 55.0	99 21	166.4	64 24.6	99 21	166.2	64 53.8	99 21	166.0	65 23.4	99 22	165.7	65 52.6	98 22	165.5	6
7	62 14.7	98 23	164.9	62 44.1	98 23	164.7	63 13.3	98 23	164.5	63 42.6	98 24	164.2	64 11.9	98 24	163.9	64 41.0	98 24	163.6	65 10.2	98 25	163.4	65 39.3	97 25	163.1	7
8	62 01.1	97 25	162.8	62 30.3	97 26	162.5	62 59.3	97 26	162.3	63 28.4	97 27	162.0	63 57.4	97 27	161.7	64 26.3	97 27	161.4	64 55.3	97 28	161.1	65 24.1	96 28	160.8	8
9	61 45.8	96 28	160.8	62 14.8	96 28	160.5	62 43.6	96 29	160.3	63 12.4	96 29	159.9	63 41.1	96 30	159.6	64 09.8	96 30	159.3	64 38.5	96 31	159.0	65 07.1	95 31	158.6	9
10	61 28.9	96 31	158.9	61 57.7	95 31	158.5	62 26.1	95 32	158.2	62 54.8	95 32	157.9	63 23.2	95 33	157.6	63 51.7	95 33	157.2	64 20.0	95 33	156.8	64 48.3	94 34	156.4	10
1	61 10.4	95 33	156.9	61 38.9	94 34	156.6	62 07.1	94 34	156.3	62 35.5	94 35	155.9	63 03.6	94 35	155.5	63 31.8	93 36	155.1	63 59.9	93 36	154.7	64 27.8	93 37	154.3	1
2	60 50.4	94 36	155.0	61 18.6	93 36	154.6	61 46.5	93 37	154.3	62 14.6	93 37	153.9	62 42.4	93 38	153.5	63 10.3	92 38	153.1	63 38.0	92 39	152.7	64 05.7	92 39	152.2	2
3	60 28.9	93 38	153.1	60 56.8	92 39	152.7	61 24.4	92 39	152.3	61 52.2	92 40	151.9	62 19.7	92 40	151.5	62 47.3	91 41	151.1	63 14.6	91 41	150.6	63 42.0	91 42	150.1	3
4	60 06.0	92 40	151.3	60 33.6	91 41	150.9	61 00.8	91 41	150.4	61 28.4	91 42	150.0	61 55.4	91 42	149.6	62 22.8	90 43	149.1	62 49.8	90 44	148.6	63 16.8	90 44	148.1	4
15	59 41.7	91 43	149.5	60 09.0	90 43	149.0	60 35.9	90 44	148.6	61 03.1	90 44	148.2	61 29.9	90 45	147.7	61 56.9	89 45	147.2	62 23.5	89 46	146.7	62 50.2	88 47	146.2	15
6	59 16.1	90 45	147.7	59 43.1	89 45	147.3	60 09.7	89 46	146.8	60 36.5	89 46	146.4	61 03.0	89 47	145.9	61 29.6	88 47	145.4	61 56.0	88 48	144.9	62 22.2	87 49	144.3	6
7	58 49.2	89 47	146.0	59 15.9	88 47	145.6	59 42.1	88 48	145.1	60 08.7	87 48	144.6	60 34.7	87 49	144.1	61 01.1	87 50	143.6	61 27.0	87 50	143.1	61 52.9	86 51	142.6	7
8	58 21.1	88 49	144.3	58 47.5	87 49	143.9	59 13.4	87 50	143.4	59 39.6	86 50	142.9	60 05.4	86 51	142.4	60 31.3	85 51	141.9	60 56.9	85 52	141.4	61 22.5	85 53	140.9	8
9	57 51.8	86 50	142.7	58 17.9	86 51	142.2	58 43.5	86 52	141.7	59 09.4	85 52	141.2	59 34.7	85 53	140.7	60 00.4	84 53	140.2	60 25.6	84 54	139.7	60 50.9	83 55	139.2	9
20	57 21.6	85 52	141.1	57 47.2	85 53	140.6	58 12.5	85 53	140.1	58 38.1	84 54	139.6	59 03.1	84 54	139.1	59 28.4	83 55	138.6	59 53.3	83 56	138.0	60 18.1	82 56	137.4	20
1	56 50.2	84 54	139.6	57 15.5	84 54	139.1	57 40.5	84 55	138.6	58 05.7	83 56	138.0	58 30.5	83 56	137.5	58 55.3	82 57	137.0	59 19.9	82 57	136.4	59 44.4	81 58	135.9	1
2	56 17.8	83 56	138.1	56 42.8	83 56	137.5	57 07.5	83 57	137.0	57 32.3	82 57	136.5	57 56.7	82 58	136.0	58 21.3	81 58	135.2	58 45.5	81 59	134.8	59 09.7	80 59	134.3	2
3	55 44.5	82 57	136.6	56 09.2	82 57	136.1	56 33.5	82 58	135.6	56 58.0	81 58	135.0	57 22.1	81 59	134.5	57 46.3	80 60	133.9	58 10.2	80 60	133.3	58 34.0	79 61	132.8	3
4	55 10.2	81 58	135.2	55 34.7	80 59	134.6	55 58.7	80 59	134.1	56 22.9	80 60	133.6	56 46.6	80 61	133.0	57 10.5	79 61	132.5	57 34.1	79 62	131.9	57 57.5	78 62	131.3	4
25	54 35.2	80 60	133.8	54 59.3	79 60	133.3	55 23.0	79 61	132.7	55 46.8	78 61	132.2	56 10.2	78 62	131.6	56 33.8	77 62	131.1	56 57.0	77 63	130.5	57 20.2	76 63	129.9	25
6	53 59.3	79 61	132.4	54 23.1	78 62	131.9	54 46.5	78 62	131.4	55 10.0	77 63	130.9	55 33.2	77 63	130.3	55 56.4	76 64	129.7	56 19.4	76 64	129.1	56 42.1	75 65	128.5	6
7	53 22.6	78 62	131.1	53 46.1	77 63	130.6	54 09.2	77 63	130.0	54 32.4	76 64	129.5	54 55.3	76 64	128.9	55 18.2	75 65	128.4	55 40.8	75 65	127.8	56 03.3	74 66	127.2	7
8	52 45.2	77 63	129.8	53 08.4	76 64	129.3	53 31.3	76 65	128.8	53 54.2	75 65	128.2	54 16.7	75 65	127.6	54 39.3	74 66	127.1	55 01.6	74 66	126.5	55 23.8	73 67	125.9	8
9	52 07.1	76 64	128.6	52 30.0	75 65	128.1	52 52.5	75 65	127.5	53 15.2	74 66	127.0	53 37.5	74 66	126.4	53 59.8	73 67	125.8	54 21.8	73 67	125.2	54 43.7	72 68	124.7	9
30	51 28.4	75 66	127.4	51 51.0	74 66	126.9	52 13.3	74 66	126.3	52 35.6	73 67	125.8	52 57.7	73 67	125.2	53 19.6	72 68	124.6	53 41.4	72 68	124.0	54 02.9	71 69	123.4	30
1	50 49.0	75 67	126.2	51 11.3	74 67	125.7	51 33.4	74 67	125.1	51 55.4	73 68	124.6	52 17.2	73 68	124.0	52 38.9	71 69	123.4	53 00.4	71 69	122.8	53 21.6	70 70	122.3	1
2	50 09.0	74 67	125.0	50 31.1	73 68	124.5	50 52.9	73 68	124.0	51 14.7	72 69	123.4	51 36.2	72 69	122.8	51 57.6	71 70	122.3	52 18.8	71 70	121.7	52 39.8	70 70	121.1	2
3	49 28.5	73 68	123.9	49 50.3	72 69	123.4	50 11.8	72 69	122.8	50 33.4	71 70	122.3	50 54.6	71 70	121.7	51 15.8	70 70	121.2	51 36.7	70 71	120.6	51 57.5	69 71	120.0	3
4	48 47.4	72 69	122.8	49 09.0	71 70	122.3	49 30.2	71 70	121.8	49 51.6	70 70	121.2	50 12.5	70 71	120.6	50 33.5	69 71	120.1	50 54.1	69 72	119.5	51 14.7	68 72	118.9	4
35	48 05.9	71 70	121.8	48 27.2	70 70	121.3	48 48.2	70 71	120.7	49 09.3	69 71	120.2	49 30.0	69 71	119.6	49 50.7	68 72	119.0	50 11.1	68 72	118.4	50 31.4	67 73	117.9	35
6	47 23.9	70 71	120.7	47 44.9	69 71	120.2	48 05.7	69 71	119.6	48 26.5	68 72	119.1	48 47.1	68 72	118.5	49 07.5	67 73	118.0	49 27.8	67 73	117.4	49 47.8	66 73	116.9	6
7	46 41.4	70 72	119.7	47 02.2	69 72	119.2	47 22.8	69 72	118.6	47 43.4	68 73	118.1	48 03.6	68 73	117.5	48 23.9	67 73	117.0	48 43.9	67 74	116.4	49 03.7	66 74	115.9	7
8	45 58.4	69 72	118.7	46 19.1	68 72	118.2	46 39.4	68 73	117.6	46 59.8	67 73	117.1	47 19.8	67 73	116.6	47 39.9	66 74	116.0	47 59.7	66 74	115.4	48 19.3	65 74	114.9	8
9	45 15.2	68 73	117.7	45 35.6	67 73	117.2	45 55.7	67 73	116.7	46 15.9	66 74	116.2	46 35.7	66 74	115.6	46 55.5	65 74	115.1	47 15.2	65 75	114.5	47 34.6	64 75	114.0	9
40	44 31.4	67 73	116.8	44 51.7	67 74	116.3	45 11.6	67 74	115.7	45 31.6	66 74	115.2	45 51.2	66 75	114.7	46 10.8	64 75	114.2	46 30.2	64 75	113.6	46 49.5	63 76	113.0	40
1	43 47.4	67 74	115.8	44 07.4	66 74	115.3	44 27.2	66 75	114.8	44 46.9	65 75	114.2	45 06.4	65 75	113.7	45 25.8	64 75	113.2	45 45.0	64 76	112.6	46 04.1	63 76	112.1	1
2	43 03.0	67 75	114.9	43 22.8	66 75	114.4	43 42.4	65 75	113.9	44 02.0	64 75	113.4	44 21.2	64 76	112.8	44 40.5	63 76	112.3	44 59.4	63 76	111.8	45 18.4	62 77	111.3	2
3	42 18.2	66 75	114.1	42 37.9	65 75	113.6	42 57.3	65 75	113.0	43 16.7	64 76	112.5	43 35.8	64 76	112.0	43 54.9	63 76	111.5	44 13.7	63 77	110.9	44 32.4	62 77	110.4	3
4	41 33.2	65 75	113.2	41 52.7	64 76	112.7	42 12.0	64 76	112.2	42 31.2	63 76	111.7	42 50.1	63 76	111.1	43 09.0	62 77	110.6	43 27.7	62 77	110.0	43 46.2	61 77	109.5	4

45	40 47.9 64 76 112.3	41 07.2 64 76 111.8	41 26.3 64 77 111.3	41 45.3 63 77 110.8	42 04.2 63 77 110.3	42 22.9 62 77 109.8	42 41.4 62 77 109.2	42 59.8 61 78 108.7	45
6	40 02.3 64 76 111.5	40 21.5 63 77 111.0	40 40.3 63 77 110.5	40 59.3 62 77 110.0	41 17.9 62 77 109.5	41 36.5 61 78 109.0	41 54.9 61 78 108.4	42 13.1 60 78 107.9	6
7	39 16.5 63 77 110.7	39 35.5 63 77 110.2	39 54.2 63 77 109.7	40 12.9 62 77 109.1	40 31.5 62 78 108.6	40 49.9 61 78 108.1	41 08.1 61 78 107.6	41 26.2 60 78 107.1	7
8	38 30.4 63 77 109.9	38 49.2 62 77 109.4	39 07.8 62 78 108.9	39 26.4 61 78 108.4	39 44.8 61 78 107.8	40 03.1 60 78 107.3	40 21.2 60 79 106.8	40 39.1 59 79 106.3	8
9	37 44.1 62 78 109.1	38 02.7 62 78 108.6	38 21.2 62 78 108.1	38 39.7 61 78 107.6	38 57.9 61 78 107.1	39 16.0 60 78 106.6	39 34.0 60 79 106.0	39 51.9 59 79 105.5	9
50	36 57.5 62 78 108.3	37 16.1 61 78 107.8	37 34.4 61 78 107.3	37 52.7 60 78 106.8	38 10.8 60 79 106.3	38 28.9 59 79 105.8	38 46.7 59 79 105.3	39 04.4 58 79 104.8	50
1	36 10.8 62 78 107.6	36 29.2 61 78 107.1	36 47.4 61 79 106.6	37 05.6 60 79 106.1	37 23.6 60 79 105.6	37 41.5 59 79 105.1	37 59.2 59 79 104.6	38 16.8 58 79 104.1	1
2	35 23.8 61 78 106.8	35 42.1 60 79 106.3	36 00.2 60 79 105.8	36 18.3 60 79 105.3	36 36.1 60 79 104.8	36 53.9 59 79 104.3	37 11.6 59 80 103.8	37 29.1 58 80 103.3	2
3	34 36.7 61 79 106.1	34 54.8 60 79 105.6	35 12.8 60 79 105.1	35 30.8 59 79 104.6	35 48.5 59 79 104.1	36 06.2 58 80 103.6	36 23.8 58 80 103.1	36 41.2 58 80 102.6	3
4	33 49.3 60 79 105.4	34 07.4 60 79 104.9	34 25.3 60 79 104.4	34 43.1 59 79 103.9	35 00.8 59 80 103.4	35 18.4 58 80 102.9	35 35.9 58 80 102.4	35 53.2 57 80 101.9	4
55	33 01.8 60 79 104.6	33 19.8 59 79 104.2	33 37.6 59 80 103.7	33 55.4 58 80 103.2	34 12.9 58 80 102.7	34 30.4 58 80 102.2	34 47.8 58 80 101.7	35 05.0 57 80 101.2	55
6	32 14.2 60 80 103.9	32 32.1 59 80 103.5	32 49.8 59 80 103.0	33 07.4 58 80 102.5	33 24.9 58 80 102.0	33 42.3 57 80 101.5	33 59.6 57 80 101.0	34 16.7 57 80 100.5	6
7	31 26.4 59 80 103.2	31 44.2 59 80 102.8	32 01.8 59 80 102.3	32 19.4 58 80 101.8	32 36.8 58 80 101.3	32 54.1 57 80 100.9	33 11.3 57 81 100.4	33 28.4 56 81 99.9	7
8	30 38.6 59 80 102.6	30 56.2 58 80 102.1	31 13.8 58 80 101.6	31 31.2 58 80 101.2	31 48.5 58 80 100.7	32 05.8 57 81 100.2	32 22.9 57 81 99.7	32 39.9 56 81 99.2	8
9	29 50.5 59 80 101.9	30 08.1 58 80 101.4	30 25.5 58 80 100.9	30 42.9 57 80 100.4	31 00.2 57 81 100.0	31 17.4 56 81 99.5	31 34.4 56 81 99.0	31 51.3 56 81 98.6	9
60	29 02.3 58 80 101.2	29 19.9 58 81 100.8	29 37.2 58 81 100.3	29 54.6 57 81 99.8	30 11.7 57 81 99.3	30 28.8 56 81 98.9	30 45.8 56 81 98.4	31 02.7 56 81 97.9	60
1	28 14.1 58 81 100.6	28 31.5 58 81 100.1	28 48.8 58 81 99.6	29 06.1 57 81 99.2	29 23.2 57 81 98.7	29 40.2 56 81 98.3	29 57.2 56 81 97.8	30 14.0 56 81 97.3	1
2	27 25.7 58 81 99.9	27 43.1 57 81 99.5	28 00.3 57 81 99.0	28 17.5 57 81 98.6	28 34.6 57 81 98.1	28 51.5 56 81 97.6	29 08.4 56 81 97.1	29 25.2 56 81 96.7	2
3	26 37.3 58 81 99.3	26 54.6 57 81 98.9	27 11.8 57 81 98.4	27 28.9 56 81 97.9	27 45.9 56 81 97.4	28 02.8 56 81 97.0	28 19.7 56 81 96.5	28 36.3 55 81 96.0	3
4	25 48.6 58 81 98.6	26 06.0 57 81 98.2	26 23.0 57 81 97.7	26 40.1 56 81 97.3	26 57.1 56 81 96.8	27 14.0 56 81 96.4	27 30.7 56 81 95.9	27 47.4 55 81 95.4	4
65	25 00.1 57 81 98.0	25 17.3 57 81 97.6	25 34.3 57 81 97.1	25 51.4 56 81 96.7	26 08.3 56 81 96.2	26 25.1 56 81 95.8	26 41.8 56 81 95.3	26 58.5 55 82 94.8	65
6	24 11.4 57 81 97.4	24 28.5 57 81 97.0	24 45.5 57 81 96.5	25 02.5 56 81 96.1	25 19.4 56 82 95.6	25 36.2 55 82 95.1	25 52.9 55 82 94.6	26 09.5 55 82 94.2	6
7	23 22.6 57 81 96.8	23 39.7 57 81 96.3	23 56.7 57 82 95.8	24 13.6 56 81 95.4	24 30.4 56 82 95.0	24 47.2 55 82 94.5	25 03.9 55 82 94.0	25 20.4 55 82 93.6	7
8	22 33.7 57 81 96.1	22 50.8 57 81 95.7	23 07.7 57 81 95.2	23 24.6 56 81 94.8	23 41.4 56 82 94.3	23 58.2 55 82 93.9	24 14.8 55 82 93.4	24 31.4 55 82 93.0	8
9	21 44.9 57 82 95.5	22 01.9 56 82 95.1	22 18.8 56 82 94.6	22 35.7 56 82 94.2	22 52.4 56 82 93.7	23 09.1 55 82 93.3	23 25.8 55 82 92.8	23 42.3 55 82 92.4	9
70	20 55.9 57 82 94.9	21 12.9 56 82 94.5	21 29.8 56 82 94.0	21 46.6 56 82 93.6	22 03.4 56 82 93.2	22 20.0 55 82 92.8	22 36.7 55 82 92.3	22 53.1 55 82 91.9	70
1	20 06.9 56 82 94.3	20 23.9 56 82 93.9	20 40.7 56 82 93.4	20 57.6 56 82 93.0	21 14.2 56 82 92.6	21 30.9 55 82 92.2	21 47.5 55 82 91.7	22 04.0 55 82 91.3	1
2	19 17.9 56 82 93.7	19 34.8 56 82 93.3	19 51.7 56 82 92.8	20 08.5 56 82 92.4	20 25.1 56 82 92.0	20 41.8 55 82 91.6	20 58.3 55 82 91.1	21 14.9 55 82 90.7	2
3	18 28.8 56 82 93.1	18 45.8 56 82 92.7	19 02.5 56 82 92.3	19 19.3 56 82 91.9	19 36.0 56 82 91.4	19 52.7 55 82 91.0	20 09.2 55 82 90.5	20 25.7 55 82 90.1	3
4	17 39.7 56 82 92.6	17 56.6 56 82 92.2	18 13.4 56 82 91.7	18 30.2 56 82 91.3	18 46.9 56 82 90.8	19 03.5 55 82 90.4	19 20.1 55 82 89.9	19 36.6 55 82 89.5	4
75	16 50.6 56 82 92.0	17 07.5 56 82 91.6	17 24.3 56 82 91.1	17 41.1 56 82 90.7	17 57.7 56 82 90.2	18 14.4 55 82 89.8	18 30.9 55 82 89.4	18 47.4 55 82 89.0	75
6	16 01.5 56 82 91.4	16 18.4 56 82 91.0	16 35.2 56 82 90.5	16 51.9 56 82 90.1	17 08.6 56 82 89.7	17 25.2 55 82 89.3	17 41.8 55 82 88.8	17 58.3 55 82 88.4	6
7	15 12.4 56 82 90.8	15 29.2 56 82 90.4	15 46.0 56 82 90.0	16 02.8 56 82 89.6	16 19.4 56 82 89.1	16 36.1 55 82 88.7	16 52.6 55 82 88.2	17 09.2 55 82 87.8	7
8	14 23.2 56 82 90.2	14 40.1 56 82 89.8	14 56.8 56 82 89.4	15 13.6 56 82 89.0	15 30.3 56 82 88.5	15 47.0 55 82 88.1	16 03.5 55 82 87.7	16 20.1 55 82 87.3	8
9	13 34.1 56 82 89.7	13 50.9 56 82 89.3	14 07.7 56 82 88.8	14 24.5 56 82 88.4	14 41.2 56 82 88.0	14 57.8 55 82 87.6	15 14.5 55 82 87.1	15 31.0 55 82 86.7	9
80	12 44.9 56 82 89.1	13 01.8 56 82 88.7	13 18.6 56 82 88.3	13 35.4 56 82 87.9	13 52.1 56 82 87.4	14 08.7 55 82 87.0	14 25.4 55 82 86.5	14 41.9 55 82 86.1	80
1	11 55.8 56 82 88.5	12 12.7 56 82 88.1	12 29.5 56 82 87.7	12 46.3 56 82 87.3	13 03.0 56 82 86.8	13 19.7 55 82 86.4	13 36.4 55 82 86.0	13 52.9 55 82 85.6	1
2	11 06.7 56 82 88.0	11 23.6 56 82 87.6	11 40.4 56 82 87.1	11 57.2 56 82 86.7	12 13.9 56 82 86.3	12 30.6 55 82 85.9	12 47.3 55 82 85.4	13 03.9 55 81 85.0	2
3	10 17.6 56 82 87.4	10 34.5 56 82 87.0	10 51.3 56 82 86.6	11 08.1 56 82 86.2	11 24.9 56 82 85.7	11 41.6 55 81 85.3	11 58.4 55 82 84.8	12 15.0 55 81 84.4	3
4	9 28.4 56 82 86.8	9 45.4 56 82 86.4	10 02.2 56 82 86.0	10 19.1 56 82 85.6	10 35.9 56 82 85.2	10 52.7 55 81 84.8	11 09.4 55 81 84.3	11 26.1 55 81 83.9	4
85	8 39.4 56 82 86.3	8 56.4 56 82 85.9	9 13.2 56 82 85.4	9 30.1 56 81 85.0	9 46.9 56 81 84.6	10 03.8 56 81 84.2	10 20.5 56 81 83.7	10 37.3 56 81 83.3	85
6	7 50.4 57 82 85.7	8 07.4 56 82 85.3	8 24.2 56 81 84.8	8 41.2 56 81 84.4	8 58.0 56 81 84.0	9 14.9 56 81 83.6	9 31.7 56 81 83.2	9 48.5 56 81 82.8	6
7	7 01.4 57 81 85.1	7 18.4 57 81 84.7	7 35.3 57 81 84.3	7 52.3 57 81 83.9	8 09.2 57 81 83.5	8 26.1 56 81 83.1	8 43.0 56 81 82.6	8 59.7 56 81 82.2	7
8	6 12.5 57 81 84.6	6 29.5 57 81 84.2	6 46.5 57 81 83.7	7 03.4 57 81 83.4	7 20.4 57 81 82.9	7 37.3 57 81 82.5	7 54.2 57 81 82.1	8 11.1 57 81 81.7	8
9	5 23.5 57 81 84.0	5 40.6 57 81 83.6	5 57.6 57 81 83.2	6 14.7 57 81 82.8	6 31.7 57 81 82.3	6 48.6 57 81 81.9	7 05.6 57 81 81.5	7 22.5 57 81 81.1	9
90			5 08.8 57 81 82.6	5 25.9 57 81 82.2	5 43.0 57 81 81.8	6 00.0 57 81 81.4	6 17.0 57 81 81.0	6 34.0 57 81 80.6	90

FIG. 273.—A page from H.O.214.

Lat. 35°

DECLINATION CONTRARY NAME TO LATITUDE

H.A.	8° 00′				8° 30′				9° 00′				9° 30′			
°	Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °
00	47 00.0	1.0	01	180.0	46 30.0	1.0	01	180.0	46 00.0	1.0	01	180.0	45 30.0	1.0	01	180.0
1	46 59.3	1.0	03	178.6	46 29.4	1.0	03	178.6	45 59.4	1.0	03	178.6	45 29.4	1.0	03	178.6
2	46 57.5	1.0	05	177.1	46 27.5	1.0	05	177.1	45 57.6	1.0	05	177.2	45 27.6	1.0	05	177.2
3	46 54.4	1.0	07	175.7	46 24.4	1.0	07	175.7	45 54.5	1.0	07	175.7	45 24.6	1.0	07	175.7
4	46 50.0	1.0	09	174.2	46 20.1	1.0	09	174.2	45 50.2	1.0	09	174.3	45 20.4	1.0	09	174.3
05	46 44.4	1.0	11	172.8	46 14.6	1.0	11	172.8	45 44.8	1.0	11	172.9	45 15.0	1.0	11	173.0
6	46 37.6	99	13	171.3	46 07.9	99	13	171.4	45 38.1	99	13	171.5	45 08.4	99	13	171.6
7	46 29.6	99	15	169.9	46 00.0	99	15	170.0	45 30.2	99	15	170.1	45 00.6	99	15	170.2
8	46 20.3	99	17	168.5	45 50.9	99	17	168.6	45 21.2	99	17	168.7	44 51.7	99	17	168.9
9	46 10.0	98	19	167.1	45 40.6	98	19	167.2	45 11.1	98	19	167.3	44 41.6	98	19	167.4
10	45 58.4	98	21	165.7	45 29.1	98	21	165.8	44 59.6	98	21	166.0	44 30.3	98	20	166.1
1	45 45.6	98	23	164.3	45 16.5	98	23	164.4	44 47.1	98	22	164.6	44 18.0	98	22	164.7
2	45 31.8	97	25	162.9	45 02.8	97	25	163.1	44 33.6	97	25	163.3	44 04.5	97	24	163.4
3	45 16.8	97	27	161.6	44 47.9	97	27	161.7	44 18.8	97	26	161.9	43 49.9	97	26	162.1
4	45 00.7	96	29	160.2	44 31.9	96	28	160.4	44 03.1	96	28	160.6	43 34.3	96	28	160.8
15	44 43.5	96	30	158.8	44 14.9	96	30	159.0	43 46.2	96	30	159.3	43 17.5	96	29	159.5
6	44 25.2	95	32	157.5	43 56.8	95	32	157.8	43 28.3	95	32	158.0	42 59.8	95	31	158.2
7	44 05.9	94	34	156.2	43 37.7	94	33	156.5	43 09.3	94	33	156.7	42 41.0	94	33	156.9
8	43 45.6	94	35	154.9	43 17.6	94	35	155.2	42 49.4	94	35	155.4	42 21.2	94	34	155.6
9	43 24.3	93	37	153.7	42 56.4	93	37	154.0	42 28.4	93	36	154.2	42 00.5	93	36	154.4
20	43 02.0	92	39	152.4	42 34.3	92	38	152.6	42 06.5	93	38	152.9	41 38.8	93	38	153.1
1	42 38.8	92	40	151.1	42 11.3	92	40	151.4	41 43.7	92	40	151.7	41 16.1	92	39	152.0
2	42 14.5	91	42	149.9	41 47.3	91	41	150.2	41 19.9	91	41	150.5	40 52.5	91	41	150.8
3	41 49.5	90	43	148.7	41 22.4	90	43	149.0	40 55.2	91	42	149.3	40 28.1	91	42	149.6
4	41 23.5	90	45	147.5	40 56.7	90	44	147.8	40 29.7	90	44	148.1	40 02.8	90	44	148.4
25	40 56.7	89	46	146.4	40 30.1	89	46	146.7	40 03.3	89	45	147.0	39 36.6	89	45	147.3
6	40 29.1	88	47	145.2	40 02.6	88	47	145.5	39 36.1	89	47	145.8	39 09.6	89	46	146.1
7	40 00.6	88	49	144.1	39 34.4	88	48	144.4	39 08.1	88	48	144.7	33 41.8	88	48	145.0
8	39 31.4	87	50	142.9	39 05.4	87	50	143.2	38 39.3	87	49	143.6	38 13.2	87	49	143.9
9	39 01.4	86	51	141.8	38 35.6	86	51	142.2	33 09.7	86	50	142.5	37 43.9	86	50	142.8
30	38 30.6	85	52	140.7	38 05.1	85	52	141.1	37 39.4	86	51	141.4	37 13.8	86	51	141.7
1	37 59.2	85	54	139.7	37 33.9	85	53	140.0	37 08.5	85	53	140.3	36 43.0	85	52	140.7
2	37 27.0	84	55	138.6	37 02.0	84	54	139.0	36 36.7	84	54	139.3	36 11.5	84	54	139.7
3	36 54.2	83	56	137.6	36 29.4	83	55	137.9	36 04.3	84	55	138.3	35 39.3	84	55	138.7
4	36 20.8	82	57	136.6	35 56.1	82	56	136.9	35 31.4	83	56	137.3	35 06.5	83	56	137.6
35	35 46.6	82	58	135.6	35 22.2	82	57	135.9	34 57.6	82	57	136.3	34 33.1	82	57	136.7
6	35 12.0	81	59	134.6	34 47.7	81	58	134.9	34 23.4	81	58	135.3	33 59.0	81	58	135.7
7	34 36.6	80	60	133.6	34 12.7	80	59	133.9	33 48.5	81	59	134.3	33 24.3	81	59	134.7
8	34 00.7	79	60	132.6	33 37.0	79	60	133.0	33 13.0	80	60	133.4	32 49.1	80	60	133.7
9	33 24.4	79	62	131.7	33 00.8	79	61	132.0	32 37.1	79	61	132.4	32 13.3	79	60	132.8
40	32 47.4	78	62	130.8	32 24.0	78	62	131.1	32 00.5	78	62	131.5	31 37.0	78	61	131.9
1	32 09.9	77	63	129.8	31 46.8	77	63	130.2	31 23.4	78	62	130.6	31 00.1	78	62	131.0
2	31 32.0	77	64	129.0	31 09.0	77	64	129.4	30 45.9	77	63	129.7	30 22.8	77	63	130.1
3	30 53.5	76	65	128.1	30 30.8	76	64	128.5	30 07.8	76	64	128.8	29 45.0	76	64	129.2
4	30 14.6	75	66	127.2	29 52.1	75	65	127.0	29 29.3	76	65	128.0	29 06.7	76	65	128.3

10° 00′				10° 30′				11° 00′				11° 30′				H.A.
Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °	Alt. ° ′	Δd	Δt	Az. °	°
45 00.0	1.0	01	180.0	44 30.0	1.0	01	180.0	44 00.0	1.0	01	180.0	43 30.0	1.0	01	180.0	00
44 59.4	1.0	03	178.6	44 29.4	1.0	03	178.6	43 59.5	1.0	03	178.6	43 29.4	1.0	03	178.6	1
44 57.7	1.0	05	177.2	44 27.6	1.0	05	177.2	43 57.7	1.0	05	177.3	43 27.7	1.0	05	177.3	2
44 54.7	1.0	07	175.8	44 24.7	1.0	07	175.8	43 54.8	1.0	07	175.9	43 24.8	1.0	07	175.9	3
44 50.5	1.0	09	174.4	44 20.6	1.0	09	174.5	43 50.7	1.0	09	174.6	43 20.8	1.0	09	174.6	4
44 45.1	1.0	11	173.1	44 15.3	1.0	11	173.2	43 45.4	1.0	11	173.2	43 15.5	1.0	10	173.2	05
44 38.6	99	13	171.7	44 08.8	99	13	171.7	43 39.0	99	12	171.8	43 09.2	99	12	171.9	6
44 30.9	99	15	170.3	44 01.2	99	15	170.4	43 31.5	99	14	170.5	43 01.8	99	14	170.6	7
44 22.0	99	17	169.0	43 52.4	99	16	169.1	43 22.8	99	16	169.2	42 53.2	99	16	169.3	8
44 12.0	98	19	167.6	43 42.5	98	18	167.7	43 13.0	98	18	167.8	42 43.5	98	18	168.0	9
44 00.8	98	20	166.2	43 31.5	98	20	166.4	43 02.0	98	20	166.5	42 32.7	98	20	166.7	10
43 48.6	98	22	164.9	43 19.4	98	22	165.0	42 50.0	98	22	165.2	42 20.8	98	22	165.4	1
43 35.3	97	24	163.6	43 06.2	97	24	163.8	42 37.0	97	24	163.9	42 07.8	97	23	164.0	2
43 20.8	97	26	162.3	42 51.9	97	26	162.5	42 22.7	97	25	162.6	41 53.8	97	25	162.7	3
43 05.4	96	27	161.0	42 36.5	96	27	161.2	42 07.6	96	27	161.3	41 38.7	97	27	161.5	4
42 48.8	96	29	159.7	42 20.1	96	29	159.9	41 51.4	96	29	160.1	41 22.6	96	28	160.2	15
42 31.2	95	31	158.4	42 02.7	95	31	158.6	41 34.1	95	30	158.8	41 05.5	95	30	159.0	6
42 12.6	94	33	157.1	41 44.2	94	32	157.4	41 15.8	94	32	157.6	40 47.4	94	32	157.8	7
41 53.0	94	34	155.9	41 24.8	94	34	156.1	40 56.5	94	34	156.3	40 28.3	94	33	156.5	8
41 32.4	93	36	154.6	41 04.4	93	35	154.9	40 36.3	93	35	155.1	40 08.2	93	35	155.4	9
41 10.9	93	37	153.4	40 43.1	93	37	153.7	40 15.2	93	37	153.9	39 47.3	93	36	154.1	20
40 48.5	92	39	152.2	40 20.8	92	39	152.5	39 53.1	92	38	152.7	39 25.4	92	38	153.0	1
40 25.1	92	40	151.0	39 57.6	91	40	151.3	39 30.1	92	40	151.6	39 02.6	92	39	151.9	2
40 00.8	91	42	149.8	39 33.6	91	41	150.1	39 06.3	91	41	150.4	38 38.9	91	41	150.7	3
39 35.7	90	43	148.7	39 08.7	90	43	149.0	38 41.5	90	42	149.2	38 14.4	90	42	149.5	4
39 09.7	90	45	147.6	38 42.9	89	44	147.9	38 16.0	90	44	148.1	37 49.0	90	43	148.4	25
38 43.0	89	46	146.4	38 16.3	89	46	146.7	37 49.6	89	45	147.0	37 22.9	89	45	147.3	6
38 15.3	88	47	145.3	37 48.9	88	47	145.6	37 22.4	88	46	145.9	36 55.9	88	46	146.2	7
37 47.0	87	49	144.2	37 20.8	87	48	144.5	36 54.5	87	48	144.8	36 28.2	87	47	145.1	8
37 17.8	87	50	143.1	36 51.9	86	49	143.4	36 25.8	87	49	143.7	35 59.7	87	49	144.0	9
36 48.0	86	51	142.1	36 22.2	86	51	142.4	35 56.3	86	50	142.7	35 30.5	86	60	143.0	30
36 17.5	85	52	141.0	35 51.8	85	52	141.3	35 26.2	86	51	141.7	35 00.5	86	51	142.0	1
35 46.2	85	53	140.0	35 20.8	84	53	140.3	34 55.4	85	52	140.6	34 29.9	85	52	140.9	2
35 14.2	84	54	139.0	34 49.1	84	54	139.3	34 23.9	84	54	139.6	33 58.6	84	53	139.9	3
34 41.7	83	56	138.0	34 16.7	83	55	138.3	33 51.7	84	55	138.6	33 26.6	84	54	138.9	4
34 08.3	82	56	137.0	33 43.7	82	56	137.3	33 18.8	83	56	137.6	32 54.1	83	55	137.9	35
33 34.5	82	57	136.0	33 10.0	81	57	136.3	32 45.4	82	56	136.7	32 20.8	82	56	137.0	6
33 00.1	81	58	135.0	32 35.8	80	58	135.3	32 11.5	81	58	135.7	31 47.0	81	57	136.0	7
32 25.0	80	59	134.1	32 01.0	79	59	134.4	31 36.8	81	58	134.8	31 12.6	81	58	135.1	8
31 49.5	80	60	133.2	31 25.6	78	60	133.5	31 01.7	80	59	133.9	30 37.7	80	59	134.2	9
31 13.4	79	61	132.3	30 49.7	78	61	132.6	30 26.0	79	60	133.0	30 02.2	80	60	133.3	40
30 36.7	78	62	131.4	30 13.3	78	62	131.7	29 49.8	79	61	132.1	29 26.2	79	61	132.4	1
29 59.5	78	63	130.5	29 36.3	77	62	130.8	29 13.0	78	62	131.2	28 49.7	78	62	131.5	2
29 21.9	77	63	129.6	28 58.9	76	63	129.9	28 35.8	77	63	130.3	28 12.6	77	62	130.7	3
28 43.8	76	64	128.7	28 21.0	76	64	129.1	27 58.1	77	64	129.5	27 35.1	77	63	129.8	4

DECLINATION SAME NAME AS LATITUDE

H.A.	8° 00′ Alt.		Az.	8° 30′ Alt.		Az.	9° 00′ Alt.		Az.	9° 30′ Alt.		Az.	10° 00′ Alt.		Az.	10° 30′ Alt.		Az.	11° 00′ Alt.		Az.	11° 30′ Alt.		Az.	H.A.
°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	° ′	Δd Δt	°	°
45	29 35.2	75 66	126.4	29 12.9	75 66	126.7	28 50.3	75 65	127.1	28 27.9	75 65	127.5	28 05.2	75 66	127.9	27 42.6	75 65	128.3	27 19.9	76 64	128.6	26 57.1	76 64	129.0	45
6	28 55.4	74 67	125.5	28 33.3	74 67	125.9	28 11.0	74 66	126.3	27 48.7	74 66	126.7	27 26.3	75 66	127.1	27 03.8	75 65	127.5	26 41.3	75 65	127.8	26 18.7	75 65	128.1	6
7	28 15.2	73 68	124.7	27 53.3	73 67	125.1	27 31.2	74 67	125.5	27 09.0	74 67	125.8	26 46.8	74 66	126.2	26 24.6	74 66	126.6	26 02.2	75 66	127.0	25 39.8	75 65	127.4	7
8	27 34.6	73 69	123.9	27 12.9	73 68	124.3	26 50.9	73 67	124.7	26 29.0	73 67	125.0	26 07.0	74 67	125.4	25 44.9	74 67	125.8	25 22.7	74 66	126.2	25 00.6	74 66	126.6	8
9	26 53.7	72 69	123.1	26 32.0	72 69	123.4	26 10.4	73 68	123.8	25 48.5	73 68	124.2	25 26.7	73 68	124.6	25 04.8	73 67	125.0	24 42.9	73 67	125.4	24 20.9	73 67	125.7	9
50	26 12.3	72 70	122.3	25 50.8	72 69	122.7	25 29.3	72 69	123.1	25 07.7	72 69	123.5	24 46.1	72 68	123.8	24 24.3	72 68	124.2	24 02.6	73 68	124.6	23 40.8	73 67	124.9	50
1	25 30.5	71 70	121.5	25 09.3	71 70	121.9	24 47.9	71 69	122.3	24 26.5	71 69	122.6	24 05.0	72 69	123.0	23 43.5	72 69	123.4	23 22.0	72 68	123.8	23 00.3	72 68	124.2	1
2	24 48.4	70 71	120.7	24 27.4	70 70	121.1	24 06.2	71 70	121.5	23 45.0	71 70	121.9	23 23.6	71 69	122.3	23 02.3	71 69	122.6	22 40.9	71 69	123.0	22 19.4	71 69	123.4	2
3	24 06.0	70 71	120.0	23 45.1	70 71	120.3	23 24.1	70 71	120.7	23 03.1	70 70	121.1	22 41.9	71 70	121.5	22 20.7	71 70	121.9	21 59.5	71 69	122.3	21 38.2	71 69	122.6	3
4	23 23.4	69 72	119.2	23 02.5	69 71	119.6	22 41.7	70 71	120.0	22 20.8	70 71	120.4	21 59.9	70 71	120.8	21 38.8	70 70	121.1	21 17.8	70 70	121.5	20 56.7	70 70	121.9	4
55	22 40.2	69 72	118.5	22 19.7	69 72	118.9	21 59.0	69 72	119.3	21 38.3	69 71	119.7	21 17.5	69 71	120.0	20 56.6	69 71	120.4	20 35.7	70 70	120.8	20 14.8	70 70	121.2	55
6	21 56.9	68 73	117.7	21 36.5	68 72	118.1	21 15.9	69 72	118.5	20 55.4	69 72	118.9	20 34.7	69 72	119.3	20 14.1	69 71	119.7	19 53.4	69 71	120.1	19 32.6	69 71	120.4	6
7	21 13.2	68 73	117.0	20 53.0	68 73	117.4	20 32.6	68 73	117.8	20 12.2	68 72	118.2	19 51.7	68 72	118.6	19 31.3	68 72	119.0	19 10.6	69 72	119.4	18 50.1	69 71	119.7	7
8	20 29.3	67 74	116.3	20 09.2	67 73	116.7	19 49.0	68 73	117.1	19 28.8	68 73	117.5	19 08.4	68 73	117.9	18 48.1	68 72	118.3	18 27.6	68 72	118.6	18 07.2	68 72	119.0	8
9	19 45.1	67 74	115.6	19 25.2	67 74	116.0	19 05.1	67 74	116.4	18 45.0	67 73	116.8	18 24.8	67 73	117.2	18 04.6	67 73	117.5	17 44.4	68 73	117.9	17 24.1	68 72	118.3	9
60	19 00.6	66 74	114.9	18 40.9	66 74	115.3	18 20.9	66 74	115.7	18 01.0	66 74	116.1	17 40.9	67 73	116.5	17 20.9	67 73	116.9	17 00.8	67 73	117.3	16 40.7	67 73	117.6	60
1	18 15.9	66 75	114.2	17 56.3	66 75	114.6	17 36.5	66 74	115.0	17 16.7	66 74	115.4	16 56.8	66 74	115.8	16 37.0	66 74	116.2	16 17.0	67 73	116.6	15 57.0	67 73	117.0	1
2	17 31.0	65 75	113.5	17 11.5	65 75	113.9	16 51.8	66 75	114.3	16 32.2	66 75	114.7	16 12.4	66 74	115.1	15 52.8	66 74	115.5	15 32.9	66 74	115.9	15 13.1	66 74	116.3	2
3	16 45.8	65 76	112.8	16 26.5	65 75	113.2	16 06.9	65 75	113.7	15 47.4	65 75	114.0	15 27.8	65 75	114.4	15 08.3	65 75	114.8	14 48.6	66 74	115.2	14 28.9	66 74	115.6	3
4	16 00.4	64 76	112.2	15 41.2	64 76	112.6	15 21.8	65 75	113.0	15 02.4	65 75	113.4	14 43.0	65 75	113.8	14 23.5	65 75	114.2	14 04.1	65 75	114.6	13 44.4	65 74	114.9	4
65	15 14.9	64 76	111.5	14 55.7	64 76	111.9	14 36.5	64 76	112.3	14 17.2	64 76	112.7	13 57.9	64 75	113.1	13 38.5	64 75	113.5	13 19.2	65 75	113.9	12 59.8	65 75	114.3	65
6	14 29.0	63 77	110.9	14 10.0	63 76	111.3	13 50.9	64 76	111.7	13 31.8	64 76	112.1	13 12.6	64 76	112.5	12 53.3	64 76	112.9	12 34.1	64 75	113.3	12 14.9	64 75	113.6	6
7	13 43.0	63 77	110.2	13 24.1	63 77	110.6	13 05.1	63 76	111.0	12 46.1	63 76	111.4	12 27.0	64 76	111.8	12 07.9	64 76	112.2	11 48.8	64 76	112.6	11 29.7	64 75	113.0	7
8	12 56.8	63 77	109.6	12 38.0	63 77	110.0	12 19.2	63 77	110.4	12 00.2	63 77	110.8	11 41.3	63 76	111.2	11 22.3	63 76	111.6	11 03.4	63 76	112.0	10 44.4	63 76	112.4	8
9	12 10.4	62 78	109.0	11 51.7	62 77	109.4	11 33.0	62 77	109.8	11 14.2	62 77	110.4	10 55.4	63 77	110.6	10 36.6	63 77	110.9	10 17.7	63 76	111.3	9 58.8	63 76	111.7	9
70	11 23.8	62 78	108.3	11 05.2	62 78	108.7	10 46.6	62 78	109.1	10 28.0	62 77	109.5	10 09.3	62 77	109.9	9 50.6	62 77	110.3	9 31.8	63 77	110.7	9 13.1	63 77	111.1	70
1	10 37.0	62 78	107.7	10 18.6	62 78	108.1	10 00.0	62 78	108.5	9 41.6	62 78	108.9	9 23.0	62 77	109.3	9 04.4	62 77	109.7	8 45.8	62 77	110.1	8 27.1	62 77	110.5	1
2	9 50.2	61 78	107.1	9 31.8	61 78	107.5	9 13.4	61 78	107.9	8 55.0	61 78	108.3	8 36.5	62 78	108.7	8 18.0	62 77	109.1	7 59.6	62 77	109.5	7 41.0	62 77	109.9	2
3	9 03.1	61 79	106.5	8 44.9	61 78	106.9	8 26.5	61 78	107.3	8 08.2	61 78	107.7	7 49.9	61 78	108.1	7 31.5	61 78	108.5	7 13.1	62 77	108.9	6 54.7	62 77	109.3	3
4	8 15.9	61 79	105.9	7 57.8	61 79	106.3	7 39.6	61 79	106.7	7 21.3	61 78	107.1	7 03.1	61 78	107.5	6 44.8	61 78	107.9	6 26.6	62 78	108.3	6 08.2	62 78	108.7	4
75	7 28.6	60 79	105.3	7 10.5	60 79	105.7	6 52.4	60 79	106.1	6 34.3	60 79	106.5	6 16.1	61 78	106.9	5 57.9	61 78	107.3	5 39.7	61 78	107.7	5 21.6	61 78	108.1	75
6	6 41.1	60 80	104.7	6 23.1	60 79	105.1	6 05.1	60 79	105.5	5 47.1	60 79	105.9	5 29.0	60 79	106.3	5 10.9	60 78	106.7							6
7	5 53.5	60 80	104.1	5 35.6	60 79	104.5	5 17.6	59 79	104.9																7
8	5 05.7	59 80	103.5																						8
91																5 11.4	57 81	80.8	5 28.5	57 81	80.4	5 45.5	57 80	80.0	91

FIG. 274.—A page from H.O. 214.

example t is east, and the latitude is north. The azimuth must therefore be measured from north to east, and the azimuth is also the true bearing.

Solve the following problems. Check your answers with those given.

PROBLEMS

1. The LHA of the moon is 43°; the declination is 11°N., and the assumed latitude is 35°N.

Required: Determine the true bearing and h_c of the moon.

Ans.: h_c 44°13.7′. Azimuth 110.9°. True bearing 249.1°.

2. The LHA of the planet Jupiter is 299°; the declination is 8°S., and the assumed latitude is 35°S.

Required: Determine the true bearing and h_c of Jupiter.

NOTE: Both the latitude and the declination are south.

Ans.: h_c 28°14.1′. Azimuth 100.6°. True bearing 79.4°.

3. The declination of the sun is 10°N., and the assumed latitude is 35°S. The LHA of the sun is 27°.

Required: Determine the true bearing and h_c of the sun.

NOTE: The declination and latitude are of opposite names.

Ans.: h_c 38°15.3′. Azimuth 145.3°. True bearing 325.3°.

4. The declination of Venus is 11°30′S.; the assumed latitude is 35°N., and the LHA is 18°.

Required: Determine the true bearing and h_c of Venus.

Ans.: h_c 40°28.3′. Azimuth 156.5°. True bearing 203.5°.

5. A plane is near latitude 35°N. when observations of the star Altair are taken. The meridian angle t is found to be 34°.

Required: Obtain the h_c and azimuth, using H.O. 214.

Procedure: The declination of Altair is 8°43′N. (see Fig. 238); h_c and azimuth are obtained from the tables for base values as follows: t 34°; declination 8°30′; latitude 35°.

	Altitude	Delta d	Azimuth
	49°09.0′	71	122.3°
Corr. for dec.: 13 × 71	9.2		Nil
Ans.:	49 18.2		122.3

NOTE: The correction (9.2) was added to the base value shown on the column 8°30′ because inspection of the 9° column showed that a higher declination produced, in this case, a higher altitude. The azimuths shown in each column were near enough alike to require no interpolation.

6. A plane was near 35°S. Lat., 60°W. Long. on Apr. 15, 1943, when observations of the sun were taken at $14^h21^m36^s$ GCT.

NOTE: Refer to Fig. 258 (page 220) for data regarding the sun.

Required: Obtain the h_c and true bearing of the sun.

Procedure: GHA of the sun $14^h20^m00^s$ GCT	34°57′
Corr. for 1^m36^s	24
GHA of the sun	35 21
Assumed long. (W) (subtract)	60 21
LHA of the sun	335
t equals 25°E.	
Dec. equals 9°35′N.	

Using H.O. 214 and base values, 35°Lat., declination 9°30′ (contrary name), and t 25° results in

	Altitude	Delta d	Azimuth
	39°36.6′	89	147.3°S. and E.
Corr. for dec. 5 × 89	4.5		Nil
h_c	39 32.1		147.3 S. and E.
			180.0
		True bearing	32.7

7. A plane was near 35°N. Lat., 135°W. Long. on Apr. 15, 1943, when observations of the star Alphard were taken. The time was $05^h46^m07^s$ GCT, and the observed altitude was 45°00′.

Required: Determine the true bearing and intercept.

8. A plane was near 34°40′N. Lat., 145°W. Long. on Apr. 15, 1943, when observations of the star Rigel were taken. The observed altitude was 14°02′ at $05^h49^m28^s$ GCT.

Required: Determine the true bearing and intercept.

9. A plane was near 34°30′S. Lat., 4°E. Long. on Apr. 15, 1943, when observations of the star Enif were taken. The observed altitude was 19°51′ at $04^h05^m05^s$ GCT.

Required: Determine the true bearing and intercept, and plot the resulting line of position on the chart in Fig. 275.[1]

In the preceding problems the altitude corrections have been obtained by multiplying the delta d value by the declination difference. In practice a multiplication table is used for this purpose; this table is found on the inside back cover of each volume of H.O. 214.

Use of Navigation Tables—H.O. 208 (Dreisonstok).—The crew of a plane is a group of specialists; the navigator must rely on himself should it become necessary to recheck a questionable fix. To this end, he should be thoroughly familiar with at least two methods of determining h_c and azimuth. H.O. 208 is recommended either as a principal means of determining h_c and azimuth or as a secondary check method. The preliminary Air Almanac work and the use of an assumed position are the same for either H.O. 214 or H.O. 208.

[1] Figure 275 is also contained in the pocket in the back of the book.

H.O. 208 consists of two tables totaling 61 pages. A few typical pages are reproduced in Fig. 276.

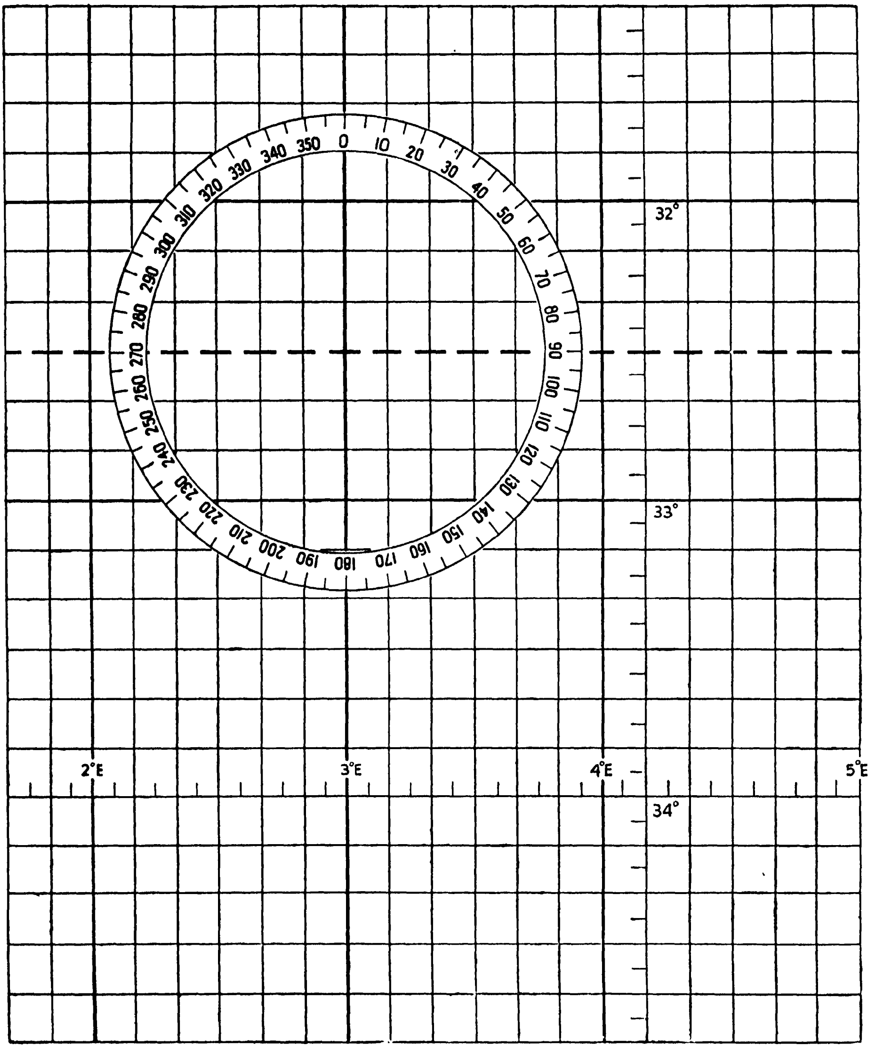


FIG. 275.—Problem 9.

The following data must be obtained before entering the tables:

t of the observed body.

Assumed latitude.

Declination of the observed body.

TABLE I

t° / L°	73° b	73° A	73° C	73° Z′	74° b	74° A	74° C	74° Z′	t° / L°
	° ′			°	° ′			°	
0	90 0.0	53406	19	90. 0	90 0.0	55966	17	90. 0	0
1	86 35.0	53336	19	86. 7	86 22.6	55887	17	86. 5	1
2	83 11.3	53126	20	83. 5	82 46.8	55646	17	83. 1	2
3	79 50.3	52779	20	80. 3	79 14.1	55254	18	79. 7	3
4	76 32.9	52306	20	77. 1	75 45.9	54717	18	76. 3	4
5	73 20.4	51708	21	74. 1	72 23.4	54048	18	73. 1	5
6	70 13.6	51006	22	71. 1	69 7.6	53258	20	70. 0	6
7	67 13.2	50205	23	68. 3	65 59.3	52362	20	67. 0	7
8	64 19.6	49316	24	65. 5	62 59.0	51373	21	64. 1	8
9	61 33.3	48356	25	62. 9	60 7.1	50308	23	61. 4	9
10	58 54.4	47335	26	60. 4	57 23.6	49183	24	58. 8	10
11	56 22.9	46263	27	58. 0	54 48.5	48005	25	56. 4	11
12	53 59.0	45151	29	55. 8	52 21.8	46794	27	54. 1	12
13	51 42.2	44012	31	53. 7	50 3.1	45551	28	51. 9	13
14	49 32.6	42850	32	51. 6	47 52.1	44294	30	49. 8	14
15	47 29.7	41673	34	49. 8	45 48.6	43026	32	47. 9	15
16	45 33.4	40489	37	48. 0	43 52.1	41756	34	46. 1	16
17	43 43.2	39302	39	46. 3	42 2.2	40489	37	44. 4	17
18	41 58.9	38123	41	44. 7	40 18.5	39231	39	42. 9	18
19	40 20.1	36948	44	43. 2	38 40.7	37984	41	41. 4	19
20	38 46.5	35782	46	41. 8	37 8.2	36753	44	40. 0	20
21	37 17.7	34632	49	40. 5	35 40.8	35537	47	38. 7	21
22	35 53.5	33499	52	39. 2	34 18.2	34345	50	37. 4	22
23	34 33.5	32381	55	38. 0	32 59.9	33173	53	36. 3	23
24	33 17.5	31284	59	36. 9	31 45.7	32023	56	35. 2	24
25	32 5.2	30207	62	35. 9	30 35.3	30898	60	34. 2	25
26	30 56.4	29150	66	34. 9	29 28.4	29798	64	33. 2	26
27	29 50.9	28115	70	34. 0	28 24.7	28721	67	32. 3	27
28	28 48.3	27102	73	33. 1	27 24.1	27670	71	31. 4	28
29	27 48.6	26112	78	32. 2	26 26.4	26645	75	30. 6	29
30	26 51.5	25147	82	31. 4	25 31.2	25646	80	29. 8	30
31	25 56.8	24202	86	30. 7	24 38.6	24669	84	29. 1	31
32	25 4.5	23281	91	30. 0	23 48.2	23718	89	28. 4	32
33	24 14.3	22381	96	29. 3	22 59.9	22791	94	27. 8	33
34	23 26.1	21505	101	28. 7	22 13.6	21890	99	27. 1	34
35	22 39.8	20651	106	28. 1	21 29.2	21012	104	26. 6	35
36	21 55.2	19820	111	27. 5	20 46.6	20158	109	26. 0	36
37	21 12.3	19008	117	26. 9	20 5.5	19328	115	25. 5	37
38	20 31.0	18220	123	26. 4	19 26.0	18519	121	25. 0	38
39	19 51.1	17452	129	25. 9	18 47.9	17732	127	24. 5	39
40	19 12.6	16704	135	25. 4	18 11.1	16969	133	24. 0	40
41	18 35.4	15979	142	25. 0	17 35.6	16226	139	23. 6	41
42	17 59.4	15272	148	24. 6	17 1.2	15503	146	23. 2	42
43	17 24.5	14586	155	24. 1	16 28.0	14802	153	22. 8	43
44	16 50.7	13919	162	23. 8	15 55.8	14122	160	22. 4	44
45	16 17.8	13270	170	23. 4	15 24.6	13461	168	22. 1	45
46	15 46.0	12641	178	23. 0	14 54.3	12820	175	21. 7	46
47	15 15.0	12029	186	22. 7	14 24.9	12198	183	21. 4	47
48	14 44.9	11437	194	22. 4	13 56.3	11595	192	21. 1	48
49	14 15.6	10863	203	22. 1	13 28.5	11010	200	20. 8	49
50	13 47.0	10306	211	21. 8	13 1.4	10443	209	20. 5	50
51	13 19.2	9765	221	21. 5	12 35.0	9894	218	20. 3	51
52	12 52.0	9242	230	21. 2	12 9.2	9362	228	20. 0	52
53	12 25.5	8736	240	20. 9	11 44.0	8848	238	19. 8	53
54	11 59.6	8246	250	20. 7	11 19.5	8351	248	19. 5	54
55	11 34.2	7773	261	20. 5	10 55.4	7869	259	19. 3	55
56	11 9.4	7315	272	20. 2	10 31.9	7404	270	19. 1	56
57	10 45.0	6871	283	20. 0	10 8.9	6956	281	18. 9	57
58	10 21.2	6445	295	19. 8	9 46.4	6523	293	18. 7	58
59	9 57.8	6033	308	19. 6	9 24.2	6106	305	18. 5	59
60	9 34.9	5637	320	19. 4	9 2.5	5704	318	18. 3	60
61	9 12.3	5255	334	19. 3	8 41.2	5317	332	18. 2	61
62	8 50.2	4888	348	19. 1	8 20.3	4945	346	18. 0	62
63	8 28.4	4535	362	18. 9	7 59.7	4588	360	17. 8	63
64	8 6.9	4197	378	18. 8	7 39.4	4245	375	17. 7	64
65	7 45.8	3873	393	18. 6	7 19.5	3917	391	17. 6	65

FIG. 276*a*.—H.O. 208.

TABLE II—$d+b$

	5°		6°		7°		8°		9°		Corr. Z''	
	h_0 5°	Z'' 84°	h_0 6°	Z'' 83°	h_0 7°	Z'' 82°	h_0 8°	Z'' 81°	h_0 9°	Z'' 80°		
	B	D	B	D	B	D	B	D	B	D	°	′
0	105970	1058	98077	978	91411	911	85644	852	80567	800	1.0	60
1	105826	1057	97957	977	91308	910	85555	851	80487	799	1.0	59
2	105683	1055	97837	976	91205	909	85465	850	80408	799	1.0	58
3	105539	1054	97717	975	91103	908	85376	849	80328	798	1.0	57
4	105397	1052	97598	974	91001	907	85286	849	80249	797	.9	56
5	105254	1051	97480	972	90899	906	85197	848	80170	796	.9	55
6	105113	1049	97361	971	90798	905	85109	847	80091	795	.9	54
7	104971	1048	97243	970	90696	904	85020	846	80012	795	.9	53
8	104830	1047	97126	969	90595	903	84931	845	79933	794	.9	52
9	104690	1045	97008	968	90494	902	84843	844	79855	793	.9	51
10	104550	1044	96891	966	90394	901	84755	843	79777	792	.8	50
11	104411	1042	96774	965	90293	900	84667	842	79698	791	.8	49
12	104272	1041	96658	964	90193	899	84579	841	79620	791	.8	48
13	104133	1040	96542	963	90093	897	84492	840	79542	790	.8	47
14	103995	1038	96426	962	89994	896	84404	840	79465	789	.8	46
15	103857	1037	96310	961	89894	895	84317	839	79387	788	.8	45
16	103720	1035	96195	959	89795	894	84230	838	79309	787	.7	44
17	103583	1034	96080	958	89696	893	84143	837	79232	787	.7	43
18	103447	1033	95966	957	89598	892	84056	836	79155	786	.7	42
19	103311	1031	95851	956	89499	891	83970	835	79078	785	.7	41
20	103175	1030	95738	955	89401	890	83884	834	79001	784	.7	40
21	103040	1029	95624	954	89303	889	83797	833	78924	783	.7	39
22	102905	1027	95510	952	89205	888	83711	832	78847	783	.6	38
23	102771	1026	95397	951	89107	887	83626	832	78771	782	.6	37
24	102637	1024	95285	950	89010	886	83540	831	78694	781	.6	36
25	102504	1023	95172	949	88913	885	83455	830	78618	780	.6	35
26	102371	1022	95060	948	88816	884	83369	829	78542	780	.6	34
27	102238	1020	94948	947	88719	884	83284	828	78466	779	.6	33
28	102106	1019	94836	946	88623	883	83199	827	78390	778	.5	32
29	101974	1018	94725	944	88526	882	83114	826	78315	777	.5	31
30	101843	1016	94614	943	88430	881	83030	826	78239	776	.5	30
31	101712	1015	94503	942	88334	880	82945	825	78164	776	.5	29
32	101581	1014	94393	941	88239	879	82861	824	78088	775	.5	28
33	101451	1012	94283	940	88143	878	82777	823	78013	774	.5	27
34	101321	1011	94173	939	88048	877	82693	822	77938	773	.4	26
35	101192	1010	94063	938	87953	876	82609	821	77863	772	.4	25
36	101063	1009	93954	937	87858	875	82526	820	77789	772	.4	24
37	100934	1007	93845	936	87764	874	82442	819	77714	771	.4	23
38	100806	1006	93736	934	87669	873	82359	819	77639	770	.4	22
39	100678	1005	93628	933	87575	872	82276	818	77565	769	.4	21
40	100550	1003	93519	932	87481	871	82193	817	77491	769	.3	20
41	100423	1002	93411	931	87388	870	82110	816	77417	768	.3	19
42	100296	1001	93304	930	87294	869	82027	815	77343	767	.3	18
43	100170	1000	93196	929	87201	868	81945	814	77269	766	.3	17
44	100044	998	93089	928	87108	867	81863	814	77195	766	.3	16
45	99918	997	92982	927	87015	866	81780	813	77122	765	.3	15
46	99793	996	92876	926	86922	865	81698	812	77048	764	.2	14
47	99668	994	92769	925	86829	864	81617	811	76975	763	.2	13
48	99544	993	92663	924	86737	863	81535	810	76902	763	.2	12
49	99419	992	92558	922	86645	862	81453	809	76829	762	.2	11
50	99296	991	92452	921	86553	861	81372	809	76756	761	.2	10
51	99172	989	92347	920	86461	861	81291	808	76683	760	.2	9
52	99049	988	92242	919	86370	860	81210	807	76610	760	.1	8
53	98926	987	92137	918	86278	859	81129	806	76538	759	.1	7
54	98804	986	92032	917	86187	858	81048	805	76465	758	.1	6
55	98682	985	91928	916	86096	857	80967	804	76393	757	.1	5
56	98560	983	91824	915	86006	856	80887	804	76321	757	.1	4
57	98439	982	91720	914	85915	855	80807	803	76248	756	.1	3
58	98318	981	91617	913	85825	854	80727	802	76177	755	.0	2
59	98197	980	91514	912	85734	853	80647	801	76105	754	.0	1
60	98077	978	91411	911	85644	852	80567	800	76033	754	.0	0
	174°		173°		172°		171°		170°			

The azimuth is reckoned from the north when in north latitude, from the south when in south latitude, toward the east when body is rising or is east of the meridian, toward the west when body is setting or is west of the meridian. **In zero latitude the azimuth takes the name of the declination.**

FIG. 276b.—H.O. 208.

TABLE II—*d*+*b*

′	10°		11°		12°		13°		14°		Corr. Z″	′
	h_o 10°	Z″ 79°	h_o 11°	Z″ 78°	h_o 12°	Z″ 77°	h_o 13°	Z″ 76°	h_o 14°	Z″ 75°		
′	B	D	B	D	B	D	B	D	B	D	°	′
0	76033	754	71940	711	68212	673	64791	637	61632	603	1.0	60
1	75961	753	71875	711	68153	672	64737	636	61582	603	1.0	59
2	75890	752	71810	710	68093	671	64682	635	61531	602	1.0	58
3	75819	751	71746	709	68034	671	64627	635	61481	602	1.0	57
4	75747	751	71681	709	67975	670	64573	634	61430	601	.9	56
5	75676	750	71616	708	67916	669	64519	634	61380	601	.9	55
6	75605	749	71552	707	67857	669	64464	633	61330	600	.9	54
7	75534	749	71488	707	67798	668	64410	633	61279	599	.9	53
8	75464	748	71423	706	67739	668	64356	632	61229	599	.9	52
9	75393	747	71359	705	67681	667	64302	631	61179	598	.9	51
10	75323	746	71295	705	67622	666	64248	631	61129	598	.8	50
11	75252	746	71231	704	67563	666	64194	630	61079	597	.8	49
12	75182	745	71167	703	67505	665	64140	630	61029	597	.8	48
13	75112	744	71104	703	67447	665	64086	629	60979	596	.8	47
14	75042	743	71040	702	67388	664	64032	629	60929	596	.8	46
15	74972	743	70976	701	67330	663	63978	628	60879	595	.8	45
16	74902	742	70913	701	67272	663	63925	628	60830	595	.7	44
17	74832	741	70850	700	67214	662	63871	627	60780	594	.7	43
18	74763	741	70786	699	67156	661	63818	626	60730	594	.7	42
19	74693	740	70723	699	67098	661	63764	626	60681	593	.7	41
20	74624	739	70660	698	67040	660	63711	625	60631	593	.7	40
21	74555	738	70597	697	66982	660	63658	625	60582	592	.7	39
22	74486	738	70534	697	66925	659	63605	624	60533	592	.6	38
23	74417	737	70471	696	66867	658	63551	624	60483	591	.6	37
24	74348	736	70409	695	66810	658	63498	623	60434	590	.6	36
25	74279	736	70346	695	66752	657	63445	622	60385	590	.6	35
26	74210	735	70284	694	66695	657	63392	622	60336	589	.6	34
27	74142	734	70221	693	66638	656	63340	621	60287	589	.6	33
28	74073	733	70159	693	66580	655	63287	621	60238	588	.5	32
29	74005	733	70097	692	66523	655	63234	620	60189	588	.5	31
30	73937	732	70034	692	66466	654	63181	620	60140	587	.5	30
31	73869	731	69972	691	66409	654	63129	619	60091	587	.5	29
32	73801	731	69910	690	66353	653	63076	619	60042	586	.5	28
33	73733	730	69849	690	66296	652	63024	618	59994	586	.5	27
34	73665	729	69787	689	66239	652	62972	617	59945	585	.4	26
35	73597	729	69725	688	66182	651	62919	617	59897	585	.4	25
36	73530	728	69664	688	66126	651	62867	616	59848	584	.4	24
37	73462	727	69602	687	66069	650	62815	616	59800	584	.4	23
38	73395	726	69541	686	66013	649	62763	615	59751	583	.4	22
39	73328	726	69479	686	65957	649	62711	615	59703	583	.4	21
40	73261	725	69418	685	65900	648	62659	614	59654	582	.3	20
41	73194	724	69357	684	65844	648	62607	614	59606	582	.3	19
42	73127	724	69296	684	65788	647	62555	613	59558	581	.3	18
43	73060	723	69235	683	65732	647	62503	612	59510	581	.3	17
44	72993	722	69174	683	65676	646	62451	612	59462	580	.3	16
45	72927	722	69113	682	65620	645	62400	611	59414	580	.3	15
46	72860	721	69053	681	65564	645	62348	611	59366	579	.2	14
47	72794	720	68992	681	65509	644	62297	610	59318	579	.2	13
48	72727	720	68932	680	65453	644	62245	610	59270	578	.2	12
49	72661	719	68871	679	65398	643	62194	609	59222	578	.2	11
50	72595	718	68811	679	65342	642	62142	609	59175	577	.2	10
51	72529	717	68750	678	65287	642	62091	608	59127	577	.2	9
52	72463	717	68690	678	65231	641	62040	608	59079	576	.1	8
53	72398	716	68630	677	65176	641	61989	607	59032	576	.1	7
54	72332	715	68570	676	65121	640	61938	606	58984	575	.1	6
55	72266	715	68510	676	65066	640	61887	606	58937	574	.1	5
56	72201	714	68451	675	65011	639	61836	605	58889	574	.1	4
57	72136	713	68391	674	64956	638	61785	605	58842	573	.1	3
58	72070	713	68331	674	64901	638	61734	604	58795	573	.0	2
59	72005	712	68272	673	64846	637	61683	604	58748	572	.0	1
60	71940	711	68212	673	64791	637	61632	603	58700	572	.0	0
	169°		168°		167°		166°		165°			

The azimuth is reckoned from the north when in north latitude, from the south when in south latitude, toward the east when body is rising or is east of the meridian, toward the west when body is setting or is west of the meridian. **In zero latitude the azimuth takes the name of the declination.**

FIG. 276*c*.—H.O. 208.

TABLE II—$d+b$

	75°		76°		77°		78°		79°		Corr. Z''	
	h_o 75°	Z'' 14°	h_o 76°	Z'' 13°	h_o 77°	Z'' 12°	h_o 78°	Z'' 11°	h_o 79°	Z'' 10°		
'	B	D	B	D	B	D	B	D	B	D	°	'
0	1506	9428	1310	9397	1128	9363	960	9327	805	9289	1.0	60
1	1502	9428	1306	9396	1125	9363	957	9327	803	9288	1.0	59
2	1499	9427	1303	9396	1122	9362	954	9326	800	9287	1.0	58
3	1495	9427	1300	9395	1119	9362	952	9326	798	9287	1.0	57
4	1492	9426	1297	9395	1116	9361	949	9325	796	9286	.9	56
5	1489	9426	1294	9394	1113	9360	946	9324	793	9285	.9	55
6	1485	9425	1291	9394	1110	9360	944	9324	791	9285	.9	54
7	1482	9425	1288	9393	1107	9359	941	9323	788	9284	.9	53
8	1479	9424	1285	9392	1104	9359	938	9322	786	9283	.9	52
9	1475	9423	1281	9392	1102	9358	936	9322	783	9283	.9	51
10	1472	9423	1278	9391	1099	9358	933	9321	781	9282	.8	50
11	1469	9422	1275	9391	1096	9357	930	9321	779	9281	.8	49
12	1465	9422	1272	9390	1093	9356	928	9320	776	9280	.8	48
13	1462	9421	1269	9390	1090	9356	925	9319	774	9280	.8	47
14	1459	9421	1266	9389	1087	9355	922	9319	771	9279	.8	46
15	1455	9420	1263	9389	1084	9355	920	9318	769	9278	.8	45
16	1452	9420	1260	9388	1081	9354	917	9317	767	9278	.7	44
17	1449	9419	1257	9388	1079	9353	914	9317	764	9277	.7	43
18	1445	9419	1254	9387	1076	9353	912	9316	762	9276	.7	42
19	1442	9418	1250	9386	1073	9352	909	9316	759	9276	.7	41
20	1439	9418	1247	9386	1070	9352	907	9315	757	9275	.7	40
21	1435	9417	1244	9385	1067	9351	904	9314	755	9274	.7	39
22	1432	9417	1241	9385	1064	9351	901	9314	752	9274	.6	38
23	1429	9416	1238	9384	1062	9350	899	9313	750	9273	.6	37
24	1426	9416	1235	9384	1059	9349	896	9312	748	9272	.6	36
25	1422	9415	1232	9383	1056	9349	894	9312	745	9271	.6	35
26	1419	9415	1229	9383	1053	9348	891	9311	743	9271	.6	34
27	1416	9414	1226	9382	1050	9348	888	9310	740	9270	.6	33
28	1412	9414	1223	9381	1047	9347	886	9310	738	9269	.5	32
29	1409	9413	1220	9381	1045	9346	883	9309	736	9269	.5	31
30	1406	9413	1217	9380	1042	9346	881	9308	733	9268	.5	30
31	1403	9412	1214	9380	1039	9345	878	9308	731	9267	.5	29
32	1399	9412	1211	9379	1036	9345	876	9307	729	9267	.5	28
33	1396	9411	1208	9379	1033	9344	873	9307	726	9266	.5	27
34	1393	9411	1205	9378	1031	9343	870	9306	724	9265	.4	26
35	1390	9410	1202	9378	1028	9343	868	9305	722	9264	.4	25
36	1386	9410	1199	9377	1025	9342	865	9305	719	9264	.4	24
37	1383	9409	1196	9376	1022	9342	863	9304	717	9263	.4	23
38	1380	9408	1193	9376	1020	9341	860	9303	715	9262	.4	22
39	1377	9408	1190	9375	1017	9340	858	9303	712	9262	.4	21
40	1373	9407	1187	9375	1014	9340	855	9302	710	9261	.3	20
41	1370	9407	1184	9374	1011	9339	853	9301	708	9260	.3	19
42	1367	9406	1181	9374	1009	9339	850	9301	706	9259	3	18
43	1364	9406	1178	9373	1006	9338	848	9300	703	9259	.3	17
44	1360	9405	1175	9373	1003	9337	845	9299	701	9258	.3	16
45	1357	9405	1172	9372	1000	9337	843	9299	699	9257	.3	15
46	1354	9404	1169	9371	0998	9336	840	9298	696	9257	.2	14
47	1351	9404	1166	9371	0995	9335	838	9297	694	9256	.2	13
48	1348	9403	1163	9370	0992	9335	835	9297	692	9255	.2	12
49	1344	9403	1160	9370	0989	9334	833	9296	690	9254	.2	11
50	1341	9402	1157	9369	0987	9334	830	9295	687	9254	.2	10
51	1338	9402	1154	9369	0984	9333	828	9295	685	9253	2	9
52	1335	9401	1151	9368	0981	9332	825	9294	683	9252	·1	8
53	1332	9401	1148	9367	0978	9332	823	9293	681	9251	1	7
54	1329	9400	1145	9367	0976	9331	820	9293	678	9251	.1	6
55	1325	9399	1142	9366	0973	9331	818	9292	676	9250	1	5
56	1322	9399	1139	9366	0970	9330	815	9291	674	9249	1	4
57	1319	9398	1136	9365	0968	9329	813	9291	672	9249	1	3
58	1316	9398	1133	9365	0965	9329	810	9290	669	9248	.0	2
59	1313	9397	1131	9364	0962	9328	808	9289	667	9247	.0	1
60	1310	9397	1128	9363	0960	9327	805	9289	665	9246	.0	0
	104°		103°		102°		101°		100°			

The azimuth is reckoned from the north when in north latitude, from the south when in south latitude, toward the east when body is rising or is east of the meridian, toward the west when body is setting or is west of the meridian. **In zero latitude the azimuth takes the name of the declination.**

FIG. 276*d*.—H.O. 208.

PROBLEMS

1. *t* equals 73°.
   Assumed latitude is 11°N.
   Declination of the sun is 20°20′N.

Required: Determine the h_c and azimuth of the sun.

Procedure: From table 1 opposite 11° Lat. and under 73° *t* (see Fig. 276) write down all the figures under columns *b*, *A*, *C*, and *Z′*.

b	*A*	*C*	*Z′*
56°22.9′N.	46263	27	58.0

Mark *b* north if the assumed latitude is in north latitude. If the assumed position is in south latitude, mark *b* south. Combine the declination with *b*, adding if both are of the same name; otherwise, subtract.

b	*A*	*C*	*Z′*
56°22.9′N.	46263	27	58.0
20 20 N. Dec.			
76 42.9			

Turn to table 2 with the value 76° at the top of the page and 43′ in the left-hand column, and add the values under *B* and *D* to *A* and *C*, respectively.

b	*A*	*C*	*Z′*
56°22.9′N.	46263	27	58.0
20 20 N. Dec.	1178*B*	9373*D*	
76 42.9	47441	9400	

Look up the number 47441 in the body of table 2 under a column headed h_c; the altitude in degrees is found at the top of the h_c column, and the minutes value is found in the left-hand column.

h_c equals 19°36′ (corresponds most nearly with 47441). Look up the number 9400 in the same table under *Z″*; the degree value is found under *Z″* (14°), and the fractional value is found under the column headed Corr. *Z″*. Add this value (14.1) to 58.0 to obtain the azimuth.

b	*A*	*C*	*Z′*
56°22.9′N.	46263	27	58.0
20 20 N. Dec.	1178 *B*	9373 *D*	14.1 *Z″*
76 42.9	47441	9400	72.1 az.

2. *t* equals 73°W.
   Assumed latitude is 51°N.
   Declination of the body is 2°10′S. h_o equals 9°.

Required: Determine the h_c, azimuth, true bearing, and intercept.

Procedure:

b	A	C	Z'
13°19.2′N.	9765	221	21.5
2 10.0 S. Dec.	71359 B	705 D	83.2 Z''
11 09.2	81124	926	104.7 az.
8°53′h_c		360°	
9 00 h_o (greater)		−104.7 az.	
7′ toward		255.3 true bearing	

TABLE II—$d+b$

′	50°		51°		52°		53°		54°		Corr. Z''	′
	h_o 50°	Z'' 39°	h_o 51°	Z'' 38°	h_o 52°	Z'' 37°	h_o 53°	Z'' 36°	h_o 54°	Z'' 35°	°	
	B	D	B	D	B	D	B	D	B	D		
35	11207	9915	10595	9899	10005	9884	9435	9868	8886	9852	.4	25
36	11197	9915	10585	9899	9995	9883	9426	9868	8877	9852	.4	24
37	11187	9914	10575	9899	9986	9883	9417	9867	8868	9851	.4	23
38	11176	9914	10565	9899	9976	9883	9408	9867	8859	9851	.4	22
39	11166	9914	10555	9898	9966	9883	9398	9867	8851	9851	.4	21
40	11156	9914	10545	9898	9957	9882	9389	9867	8842	9851	.3	20
41	11145	9913	10535	9898	9947	9882	9380	9866	8833	9850	.3	19
42	11135	9913	10525	9897	9937	9882	9370	9866	8824	9850	.3	18
43	11125	9913	10515	9897	9928	9882	9361	9866	8815	9850	.3	17
44	11114	9913	10505	9897	9918	9881	9352	9866	8806	9850	.3	16
45	11104	9912	10496	9897	9909	9881	9343	9865	8797	9849	.3	15
46	11094	9912	10486	9896	9899	9881	9333	9865	8788	9849	.2	14
47	11083	9912	10476	9896	9889	9881	9324	9865	8779	9849	.2	13
48	11073	9911	10466	9896	9880	9880	9315	9864	8770	9848	.2	12
49	11063	9911	10456	9896	9870	9880	9306	9864	8761	9848	.2	11
50	11052	9911	10446	9895	9861	9880	9296	9864	8752	9848	.2	10
51	11042	9911	10436	9895	9851	9879	9287	9864	8743	9848	.2	9
52	11032	9910	10426	9895	9841	9879	9278	9863	8734	9847	.1	8
53	11022	9910	10416	9895	9832	9879	9269	9863	8726	9847	.1	7
54	11011	9910	10406	9894	9822	9879	9259	9863	8717	9847	.1	6
55	11001	9910	10396	9894	9813	9878	9250	9863	8708	9847	.1	5
56	10991	9909	10386	9894	9803	9878	9241	9862	8699	9846	.1	4
57	10980	9909	10376	9894	9794	9878	9232	9862	8690	9846	.1	3
58	10970	9909	10367	9893	9784	9878	9223	9862	8681	9846	.0	2
59	10960	9909	10357	9893	9775	9877	9213	9862	8672	9846	.0	1
60	10950	9908	10347	9893	9765	9877	9204	9861	8664	9845	.0	0
	129°		128°		127°		126°		125°			

The azimuth is reckoned from the north when in north latitude, from the south when in south latitude, toward the east when body is rising or is east of the meridian, toward the west when body is setting or is west of the meridian. **In zero latitude the azimuth takes the name of the declination.**

b	A	C	Z′
87°-38′.1N	37375	43	87.9
38-44.0N			
126-22.1			

(d+b)

FIG. 277.—H.O. 208 procedure when $d + b$ exceeds 90°.

NOTES ON SOLUTIONS: When d plus b exceeds 90° as shown in Fig. 277, use table 2 as indicated. When this is done, Z'' must be subtracted from Z'.

When the LHA falls between the values 90 and 270°, the value of t used in table 1 is determined as shown in Fig. 278. It will be seen from the illustration, for example, that an LHA of either 135° or 225° results in a t value of 45°.

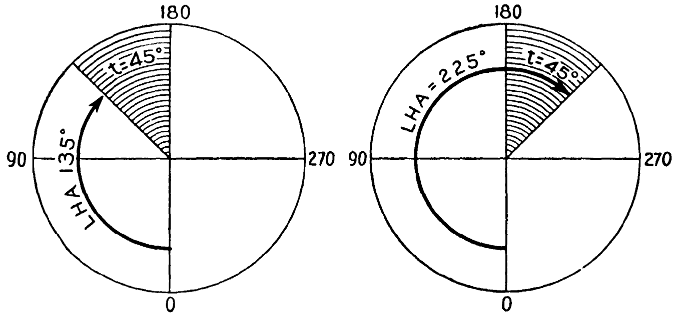


FIG. 278.—Determination of t when LHA falls between 90 and 270° (case 2).

When t is obtained in this manner, b (the first group of figures taken from table 1) is named *contrary to the assumed latitude.* The difference between Z' and Z'' becomes the azimuth.

3. t is 74°W.
   Assumed latitude is 2°N.
   Declination of the sun is 21°28′N. h_o is 15°01′.

Required: Determine h_c, azimuth, true bearing, and intercept.

Procedure:

b		*A*	*C*	*Z′*
82°46.8′N.		55646	17	83 1
21 28	N. Dec.	1356 *B*	9405 *D*	14.8 *Z″*
104 14.8		57002	9422	68.3 az.
	15°37′h_c		68.3° azimuth	
	15 01 h_o (less)		360	
	36 away		291.7 true bearing	

4. LHA equals 107°. t equals 73°W.
   Assumed latitude is 60°N.
   Declination of body is 23°20′N. h_o is 12°59′.

Required: Determine h_c, azimuth, true bearing, and intercept.

Procedure:

b		*A*	*C*	*Z′*
9°34.9′S.		5637	320	19.4
23 20	N. Dec.	62400 *B*	611 *D*	83.3 *Z″*
13 45.1		68037	931	63.9 az.
	12°03′h_c		63.9° azimuth	
	12 59 h_o (greater)		360	
	Intercept 56 toward		296.1 true bearing	

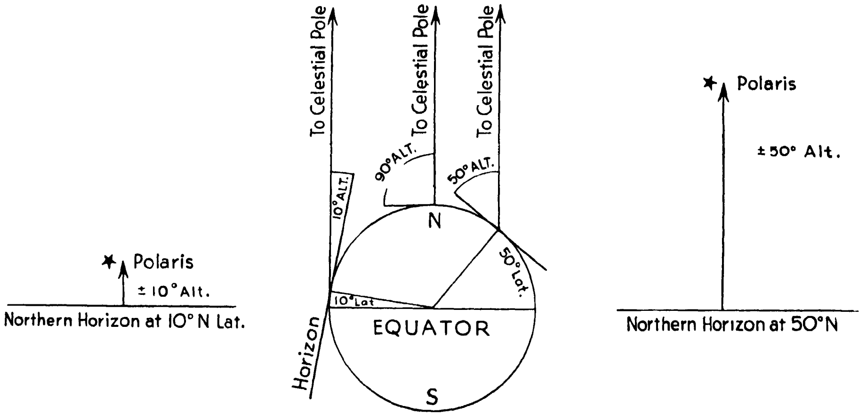


FIG. 279.—Relation between the altitude of the celestial pole and latitude.

POLARIS

LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.	LHA ♈	Corr.
° ′	′	° ′	′	° ′	′	° ′	′	° ′		° ′	′
358 56		89 43		128 40		178 28		270 37		309 39	
	−54		−26		+14		+54		+26		−14
1 02		90 46		129 39		180 37		271 41		310 37	
	−55		−25		+15		+55		+25		−15
3 20		91 48		130 38		182 56		272 43		311 36	
	−56		−24		+16		+56		+24		−16
5 52		92 50		131 37		185 31		273 46		312 35	
	−57		−23		+17		+57		+23		−17
8 45		93 52		132 36		188 27		274 48		313 34	
	−58		−22		+18		+58		+22		−18
12 11		94 53		133 36		191 57		275 49		314 34	
	−59		−21		+19		+59		+21		−19
16 47		95 53		134 37		196 37		276 50		315 34	
	−60		−20		+20		+60		+20		−20
35 41		96 53		135 37		215 51		277 51		316 34	
	−59		−19		+21		+59		+19		−21
40 16		97 53		136 38		220 31		278 51		317 34	
	−58		−18		+22		+58		+18		−22
43 42		98 53		137 39		224 00		279 51		318 35	
	−57		−17		+23		+57		+17		−23
46 35		99 52		138 41		226 56		280 50		319 37	
	−56		−16		+24		+56		+16		−24
49 07		100 51		139 44		229 31		281 49		320 39	
	−55		−15		+25		+55		+15		−25
51 25		101 50		140 46		231 51		282 48		321 41	
	−54		−14		+26		+54		+14		−26
53 31		102 48		141 50		233 59		283 47		322 44	
	−53		−13		+27		+53		+13		−27
55 30		103 47		142 54		236 00		284 46		323 48	
	−52		−12		+28		+52		+12		−28
57 21		104 45		143 58		237 53		285 44		324 52	
	−51		−11		+29		+51		+11		−29
59 07		105 42		145 04		239 40		286 42		325 56	
	−50		−10		+30		+50		+10		−30
60 48		106 40		146 10		241 23		287 40		327 02	
	−49		− 9		+31		+49		+ 9		−31
62 25		107 38		147 16		243 01		288 37		328 08	
	−48		− 8		+32		+48		+ 8		−32
63 59		108 35		148 24		244 36		289 35		329 15	
	−47		− 7		+33		+47		+ 7		−33
65 29		109 32		149 32		246 08		290 32		330 22	
	−46		− 6		+34		+46		+ 6		−34
66 57		110 30		150 42		247 36		291 30		331 31	
	−45		− 5		+35		+45		+ 5		−35
68 22		111 27		151 52		249 02		292 27		332 41	
	−44		− 4		+36		+44		+ 4		−36
69 44		112 24		153 03		250 26		293 24		333 51	
	−43		− 3		+37		+43		+ 3		−37
71 05		113 21		154 16		251 48		294 21		335 03	
	−42		− 2		+38		+42		+ 2		−38
72 24		114 18		155 30		253 08		295 18		336 16	
	−41		− 1		+39		+41		+ 1		−39
73 41		115 15		156 45		254 26		296 15		337 30	
	−40		0		+40		+40		0		−40
74 57		116 12		158 01		255 42		297 12		338 46	
	−39		+ 1		+41		+39		− 1		−41
76 11		117 09		159 19		256 58		298 09		340 03	
	−38		+ 2		+42		+38		− 2		−42
77 24		118 06		160 39		258 11		299 06		341 22	
	−37		+ 3		+43		+37		− 3		−43
78 36		119 03		162 01		259 24		300 03		342 43	
	−36		+ 4		+44		+36		− 4		−44
79 46		120 00		163 25		260 35		301 00		344 06	
	−35		+ 5		+45		+35		− 5		−45
80 56		120 57		164 51		261 46		301 57		345 31	
	−34		+ 6		+46		+34		− 6		−46
82 05		121 55		166 20		262 55		302 55		346 58	
	−33		+ 7		+47		+33		− 7		−47
83 12		122 52		167 51		264 03		303 52		348 28	
	−32		+ 8		+48		+32		− 8		−48
84 19		123 50		169 26		265 11		304 49		350 02	
	−31		+ 9		+49		+31		− 9		−49
85 25		124 47		171 04		266 17		305 47		351 39	
	−30		+10		+50		+30		−10		−50
86 31		125 45		172 47		267 23		306 45		353 20	
	−29		+11		+51		+29		−11		−51
87 36		126 43		174 34		268 29		307 43		355 06	
	−28		+12		+52		+28		−12		−52
88 40		127 42		176 27		269 33		308 41		356 57	
	−27		+13		+53		+27		−13		−53
89 43		128 40		178 28		270 37		309 39		358 56	

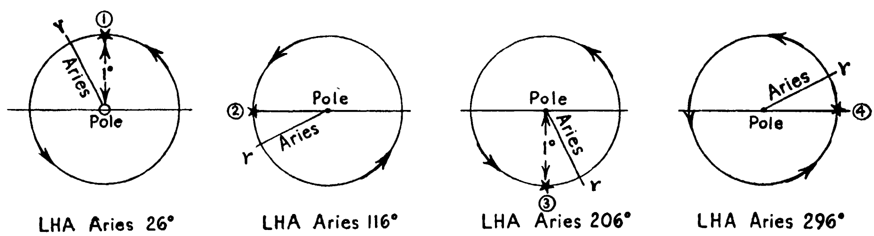
Refraction not included: Use Table A.

FIG. 280.—Polaris correction table.

NOTE: If the navigator chooses to adopt this table either as a primary or secondary means of solving for h_c and azimuth, it is recommended that all the problems given for H.O. 214 be worked out by this method as a means of gaining proficiency.

Latitude by Polaris.—The star Polaris is located approximately 1° from the north celestial pole. It is located so close to the celestial-sphere axis that its movement in the sky is imperceptible to the eye.

Figure 279 shows that the elevation (altitude) of the celestial pole above the horizon is exactly equal to the observer's latitude. The proximity of the star Polaris to this pole makes it possible to ascertain the approximate elevation of the pole and hence, even without tables, the approximate north latitude of the plane.



A B C D

FIG. 281.—Relative positions of Aries and Polaris.

Thus, for example, when the altitude of Polaris is 41°, the altitude of the north celestial pole must be between 40 and 42° and within these limits the latitude of the observer is established. Accuracy, however, of this order is unsatisfactory. The American Air Almanac contains a table that supplies the correction to be applied to an observed altitude in order to make it agree with the actual altitude of the true north celestial pole. This table is reproduced in Fig. 280. The correction is tabulated opposite the LHA of Aries.

Figure 281 shows how it is possible to tabulate this correction for the LHA of Aries rather than for the t value of Polaris. The SHA of Polaris is 333°57′, and it may be logically reasoned that for every position of the meridian of Aries around the pole there must be a corresponding position of Polaris. When the meridian of Aries is approximately 26°

west of the observer's meridian, as at *A*, Fig. 281, Polaris (334° to the westward of Aries) occupies position 1 in its orbit around the pole. With Polaris in this position any measure of altitude would be 1° too high, for Polaris is 1° from the pole. The correction table (Fig. 280) shows that a minus 1° correction takes place when the LHA of Aries is 26°. Six hours later when the meridian of Aries is 116° west of the observer's meridian, as at *B*, Fig. 281, Polaris occupies position 2. For this position of Aries there should be no correction to the observed altitude of Polaris, for it is exactly as high above the horizon as the celestial north pole. Inspection of the table shows this to be correct; 0° correction is applied when the LHA of Aries is 116°.

This establishes the point that it is necessary only to determine the LHA of Aries and measure the altitude of Polaris in order to have at hand all data required for a solution of the observer's latitude.

PROBLEMS

1. The observed altitude of Polaris is 63°10′ at 07^h00^m GCT. At this time the LHA of Aries is 321°.

Required: Determine the latitude of the observer.

Procedure:	Observed altitude	63°10′
	Corr. from Polaris table (subtract)	25
	Observer's lat.	62°45′ N.

2. Apr. 15, 1943, at $03^h05^m07^s$ GCT the observed altitude of Polaris was 39°21′. The plane was near 106°18′W. Long.

Required: The latitude of the observer.

Procedure:	GHA of Aries for $03^h00^m00^s$ GCT	247°24′
	Corr. for 05^m07^s	1 17
	GHA of Aries	248 41
	Long. W. (subtract)	106 18
	LHA of Aries	142 23

Enter the Polaris correction table with the LHA of Aries, and note the correction value (+27).

39°21′h_o
27 corr.
39 48 lat. of the observer (north)

3. At $03^h05^m07^s$ GCT, Apr. 15, 1943, the observed altitude of Polaris was 26°05′. The plane's longitude was approximately 21°17′E.

Required: What was the plane's latitude?

4. At $09^h21^m16^s$ GCT, Apr. 15, 1943, the observed altitude of Polaris was 56°29′. The plane's longitude was 179°41′E.

Required: What was the plane's latitude?

5. At $07^h53^m40^s$ GCT, Apr. 15, 1943, the observed altitude of Polaris was 17°12′. The plane's longitude was 159°20′W.

Required: What was the plane's latitude?

6. At $06^h13^m10^s$ GCT, Apr. 15, 1943, the observed altitude of Polaris was 58°18′. The plane's longitude was 31°05′W.

Required: What was the plane's latitude?

Altitudes and Horizons.—The calculated altitude h_c of a body may be obtained through the use of navigation tables such as just discussed; the true observed altitude h_o of a celestial body must be obtained by the navigator through the use of instruments. The instrument altitude must, as a rule, be corrected for certain errors before it may be termed a true observed altitude. In each of the preceding problems calling for the use of such true altitudes, instrument altitudes properly corrected for errors were supplied.

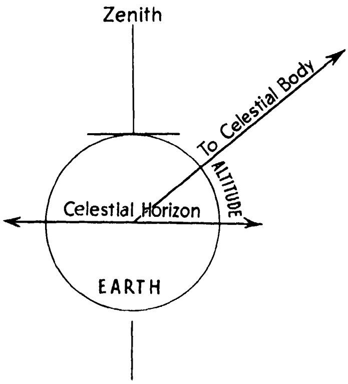


FIG. 282.—Measurement of true altitude above the celestial horizon.

The true altitude of a celestial body at any position on the earth's surface is the altitude that would be obtained by an observer at the center of the earth measuring altitudes above a plane perpendicular to his zenith and passing through the center of the earth. This plane above which true altitudes are reckoned is called the **celestial horizon.** This horizon is shown in Fig. 282, and the altitude of a celestial body is shown measured above it.

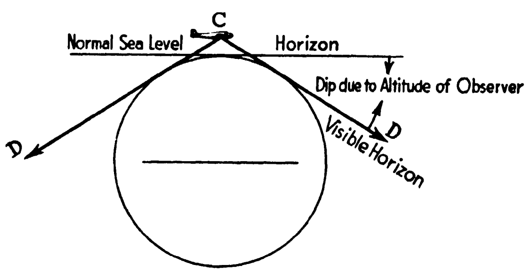


FIG. 283.—The visible horizon.

The horizon, as we are accustomed to think of it, is formed by the intersection of the sky and sea. This horizon is known as the **visible horizon,** and it varies with the height of the observer above the earth. At sea level the observer's eye looks straight out along a plane parallel to the celestial horizon; at high elevations the plane of the visible horizon

dips, as shown by the line *CD* in Fig. 283; and an altitude measured above this horizon would be too great. Occasionally, on clear days, the air navigator has an opportunity to use the visible horizon. When this is done, a negative correction must be applied to the instrument altitude according to the table shown in Fig. 284.

DIP

Subtract from altitude observed with *sea horizon.*

Height	Corr.	Height	Corr.	Height	Corr.	Height	Corr.
Ft.	′	*Ft.*	′	*Ft.*	′	*Ft.*	′
0	1	160	13	620	25	1380	37
2	2	180	14	670	26	1460	38
6	3	210	15	730	27	1540	39
12	4	250	16	780	28	1620	40
21	5	280	17	840	29	1700	41
31	6	310	18	900	30	1790	42
43	7	350	19	960	31	1870	43
58	8	390	20	1030	32	1960	44
75	9	430	21	1090	33	2060	45
93	10	480	22	1160	34	2150	46
114	11	520	23	1230	35	2250	47
137	12	570	24	1310	36	2340	48
162		620		1380		2440	

FIG. 284.—Altitude correction for the dip of the visible horizon.

For the most part, air navigators measure the altitudes of celestial bodies above an artificial horizon formed by a spirit-level unit contained in the measuring instrument. This horizon is known as the **bubble horizon,** and it indicates a plane parallel to the celestial horizon but tangent to the earth at the observer's position.

Both the celestial and the bubble horizons are shown in Fig. 285. Technically, the bubble horizon is properly termed the **sensible horizon.**

When the altitude of a distant heavenly body is measured above the bubble horizon, almost exactly the same altitude is obtained as would be

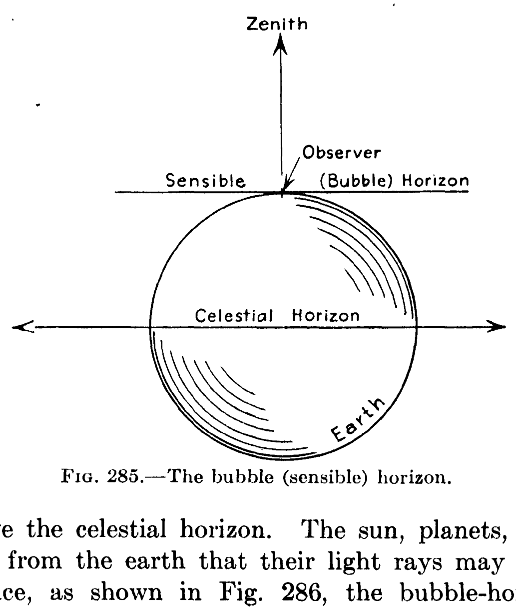


FIG. 285.—The bubble (sensible) horizon.

obtained above the celestial horizon. The sun, planets, and stars are so far distant from the earth that their light rays may be considered parallel. Hence, as shown in Fig. 286, the bubble-horizon altitude equals the celestial-horizon altitude for these bodies. The radius of the

earth separating the two horizons is small enough to be neglected in dealing with such bodies.

Moon's Parallax Correction.—The moon is so close to the earth that there is usually an appreciable difference between altitudes measured above the sensible and celestial horizons. As in the case of other celestial bodies, the *true altitude* of the moon is its altitude above the celestial horizon at the center of the earth.

Figure 287 shows that, when the moon has zero altitude with respect to the bubble (sensible) horizon, it has a very positive altitude above the celestial horizon. In the figure the moon is shown disproportionately close to the earth for the sake of emphasis. The difference between the moon's altitude above the sensible horizon and its true altitude above the celestial horizon is called the **moon's parallax.**

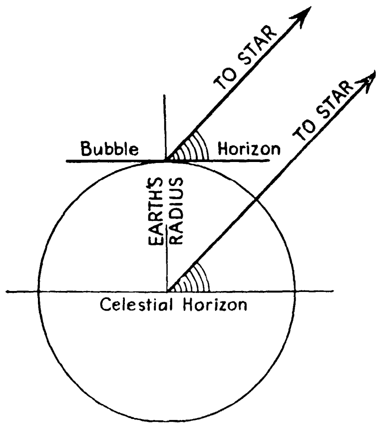


FIG. 286.—Measurement of a star's altitude above the bubble horizon.

In Fig. 288 the moon is shown at an 80° altitude and also at a 90° altitude. Notice that when the moon's altitude is 80° there is very little difference between its altitude above the sensible horizon and its altitude above the celestial horizon; *i.e.*, the parallax correction is small. At 90° there is no difference; the parallax correction is nil.

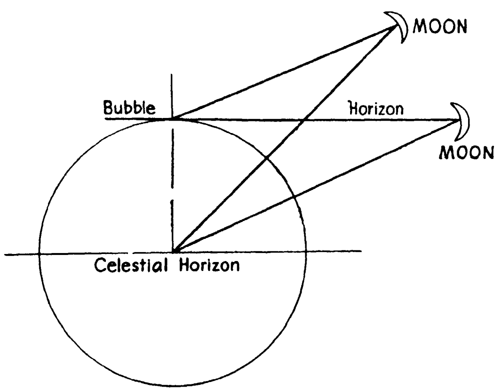


FIG. 287.—Measurement of the moon's altitude above the bubble horizon.

The exact parallax correction for the moon is found in the last column of the American Air Almanac daily sheet previously shown in Fig. 258 (page 220). According to this tabulation for Apr. 15, 1943, a +40′ correction must be applied to the moon's altitude when its altitude is between

42 and 43° above the bubble horizon. At 75° altitude the correction is +14′. These values hold good for Apr. 15, 1943, only. Larger corrections are tabulated for days when the moon is closer to the earth, and lesser corrections are tabulated when the moon is more distant.

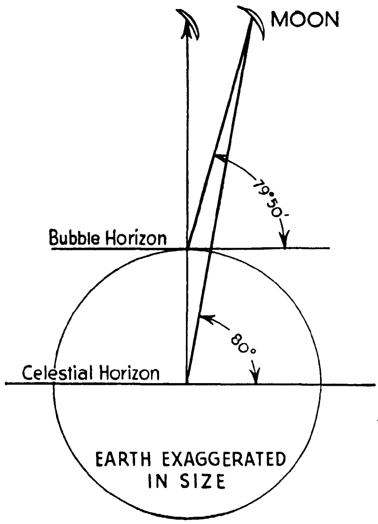


FIG. 288.—Decrease of moon's parallax with increase of altitude.

Correction of All Altitudes for Refraction.—The light from celestial bodies curves downward slightly as it passes through the earth's atmosphere. To a navigator these bodies appear slightly higher in the sky than they should because he looks out toward them in the direction last taken by their light rays. This bending phenomenon, known as **refraction,** is shown in exaggerated form in Fig. 289.

The exact amount of this refraction depends on the density of the air and also on the altitude of the celestial body. In flying near sea level, corrections are greater than in flying high. On the back cover of the American Air Almanac the precise refraction correction is set forth in tabular form, as shown in Fig. 290. The value shown is invariably subtracted from the instrument altitude of celestial bodies.

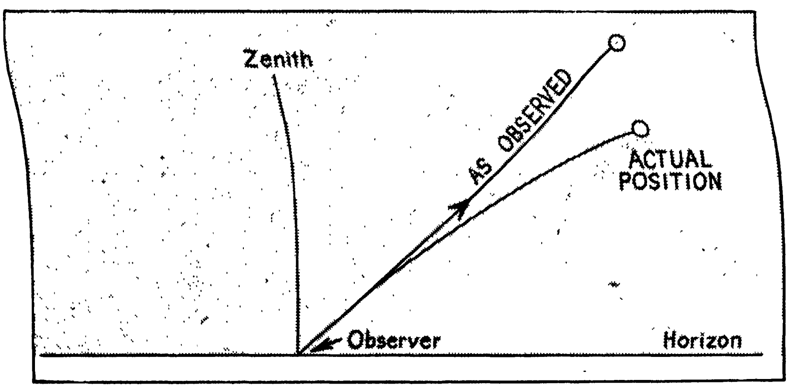


FIG. 289.—Atmospheric refraction of light rays from celestial bodies.

Summary.—Instrument altitudes of the moon above the bubble horizon are always corrected for parallax and refraction. Instrument altitudes of all other bodies above the bubble horizon are corrected

for refraction only. This summation should be borne in mind in the following problems.

REFRACTION

A. *Total correction.*—For use with H. O. 208, H. O. 209, H. O. 211, H. O. 214, and the Polaris Table. Subtract from observed altitude.

Height in feet	Observed altitude						
	5°	10°	15°	20°	30°	45°	60°
	′	′	′	′	′	′	′
0	10	5	4	3	2	1	1
5,000	8	5	3	2	1	1	0
10,000	7	4	3	2	1	1	0
15,000	6	3	2	2	1	1	0
20,000	5	3	2	1	1	1	0
25,000	4	2	2	1	1	0	0
30,000	3	2	1	1	1	0	0
35,000	3	2	1	1	1	0	0
40,000	2	1	1	1	0	0	0

FIG. 290.—Refraction correction for all bodies.

PROBLEMS

1. The observed altitude of the moon on Apr. 15, 1943, was 33°48′ as measured above the bubble horizon. The altitude of the observer was 5,000 ft.

Required: The true altitude of the moon.

Procedure:	Instrument altitude	33°48′
	Refraction corr. (subtract)	1 (Fig. 290)
		33 47
	Corr. for parallax (add)	45 (Fig. 258)
	Corrected (true) altitude	34°32′

2. The instrument altitude of the moon on Apr. 15, 1943, was 77°21′. The altitude of the observer was 1,000 ft.

Required: The true altitude of the moon.

3. The instrument altitude of the moon on Apr. 15, 1943, was 7°53′. The altitude of the plane was 15,000 ft.

Required: The true altitude of the moon.

4. The instrument altitude of the moon on Apr. 15, 1943, was 48°. The altitude of the plane was 5,000 ft.

Required: The true altitude of the moon.

5. The instrument altitude of the sun is 17°17′. The altitude of the plane is 500 ft.

Required: The true altitude of the sun.

Procedure:	Instrument altitude	17°17′
	Refraction corr. (subtract)	4 (Fig. 290)
	True altitude	17°13′

6. The instrument altitude of a star is 51°32′. The altitude of the plane is 20,000 ft.

Required: The true altitude of the star.

Procedure:	Instrument altitude	51°32′
	Refraction corr. (subtract)	00
	True altitude	51°32′

7. The instrument altitude of a planet was 5°41′. The altitude of the plane was 10,000 ft.

Required: The true altitude of the planet.

Procedure:	Instrument altitude	5°41′
	Refraction corr. (subtract)	7
	True altitude	5°34′

8. Ascertain the correction for refraction (and parallax if necessary) and determine the true altitudes:

Altitude of plane, feet	Instrument altitude	Celestial body
6,000	15°22′	Moon
5,400	71 13	Sun
12,000	38 41	Venus
500	51 27	Jupiter
20,000	80 00	Achernar
8,000	6 21	Acrux
9,000	23 21	Polaris
2,000	45 01	Moon
12,000	61 58	Vega
7,000	30 45	Moon

In the following chapter dealing with instruments, the work incidental to the determination of instrument altitudes will be taken up in detail.

CHAPTER X

USE, CARE, AND CALIBRATION OF NAVIGATION INSTRUMENTS

The Octant.—The instrument used in flight to measure celestial-body altitudes is popularly called an **octant.** Actually, it may be an octant capable of measuring angles up to 90° or a sextant capable of measuring angles up to 120°. The Pioneer octant—one of the most popular of these instruments—is shown in two views in Figs. 291*a* and 291*b*.

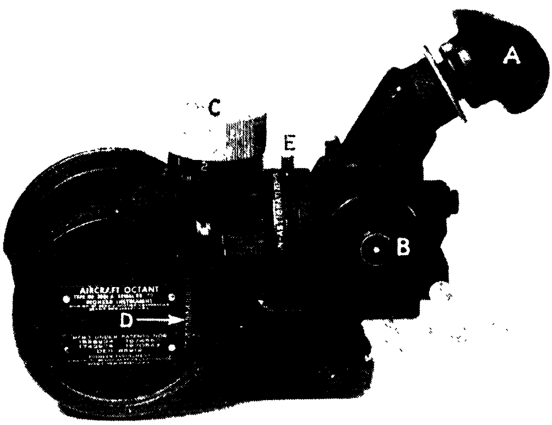


FIG. 291*a*.—Pioneer octant, left view.

While a detailed discussion of the optical principles of this instrument is not within the scope of this text, certain operational functions must be made clear since damage or inaccurate observations may otherwise result. From a navigator's standpoint the instrument consists of a rotatable eyepiece *A*; an artificial bubble horizon controlled by knob, *B*; a drum *C* by means of which the altitude measurement is controlled; colored shade glasses *D*; and an astigmatizer *E*. Normally, when the observer is able to face the celestial body, the instrument is held as shown in Fig. 292.

Forming the Bubble.—An octant is a precision instrument and as such should be handled with care, especially in forming the bubble. The bubble is formed by rotating the knurled knob *b* clockwise while the instrument is held tilted about 45° to the left (see Fig. 293). Turning this nut pulls the diaphragm *F* outward, and a partial vacuum is created in the liquid-filled chamber. The bubble resulting from this operation

passes up through channel X into the field of vision. If the diaphragm is new, a slight click will be heard when the bubble forms; the screw should be turned no farther until the bubble is seen in the instrument. Repeated application of undue stress on the diaphragm will eventually weaken and possibly break it. A slow oscillation of the octant may be

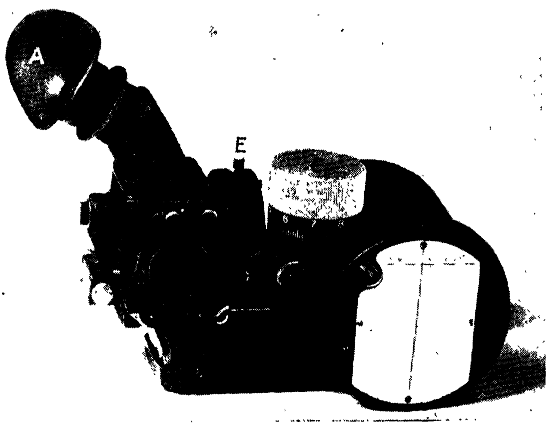


FIG. 291b.—Pioneer octant, right view.

FIG. 292.—Observing altitudes with the Pioneer octant, normal position.

required to shake the bubble loose and start it on its way up through channel X. Under no circumstances is the instrument to be pounded in order to make the bubble appear. If the bubble is too large, it may be reduced in size by turning the nut slightly in a counterclockwise direction, thus relieving some tension on the diaphragm.

The proper size bubble to use varies under different turbulence conditions. The bubble should be large enough to move freely in the

chamber without sticking and yet not so large as to be unmanageable. A size about that of the end of a pencil eraser is recommended for normal flight conditions.

Looking into the instrument in the daytime the navigator sees a bubble in the field of vision as shown at *A*, Fig. 294. At night the bubble appears as a faintly luminous ring against a black background, as at *B*.

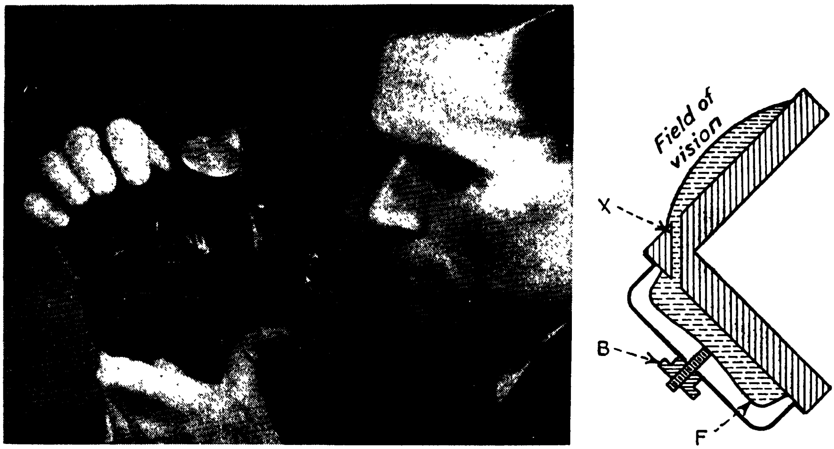


FIG. 293.—Correct position of bubble chamber when forming the bubble.

Measuring the Altitude of a Celestial Body.—After the bubble has been formed, the instrument is held in normal position as previously shown while the altitude drum is rotated to bring the celestial body into the field of vision.

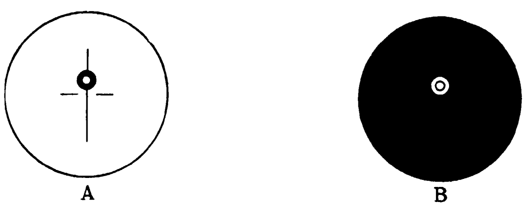


FIG. 294.—The bubble as seen in daytime and at night.

By rotating the altitude drum backward or forward the celestial-body image may be made to move up or down the field of vision parallel to the long vertical line shown at *A*, Fig. 295. The correct altitude is measured when **collimation** has been achieved, *i.e.*, when the celestial body has been brought alongside and centered beside the bubble as at *B*. The point should be stressed that the bubble itself is the artificial horizon and, as long as collimation occurs somewhere on the vertical line, the

correct altitude has been measured. Thus, correct altitudes are measured when collimation is achieved as at *C*, *D*, or *E*, Fig. 295.

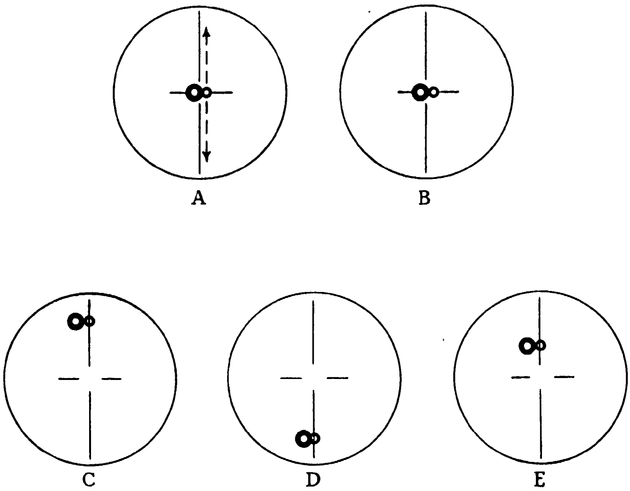


Fig. 295.—Correct bubble-image collimation.

An error of approximately 5′ of arc results when collimation is achieved with the bubble in the positions shown at *A*, *B*, *C*, *D* or *E*, Fig. 296.

In the beginning the student will experience considerable difficulty in keeping the bubble in proper position—especially in rough air. The

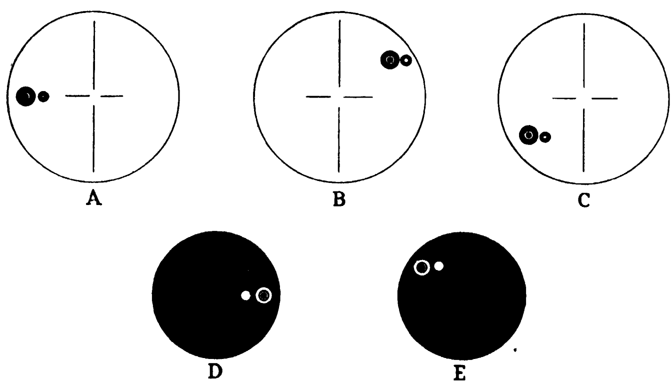


Fig. 296.—Incorrect collimation of bubble and image.

instructor cannot look through the instrument with him and cannot tell him which way to move the instrument in order to keep the bubble steady. After about 3 or 4 hr. practice, the student will himself acquire the correct habits of procedure. It is suggested that a smaller than normal bubble be used in the initial training period.

The altitude is read on the right-hand side of the instrument; tens of degrees are shown in the little window *A*, and the correct altitude is equal to this value plus the degrees and minutes of arc shown on the drum

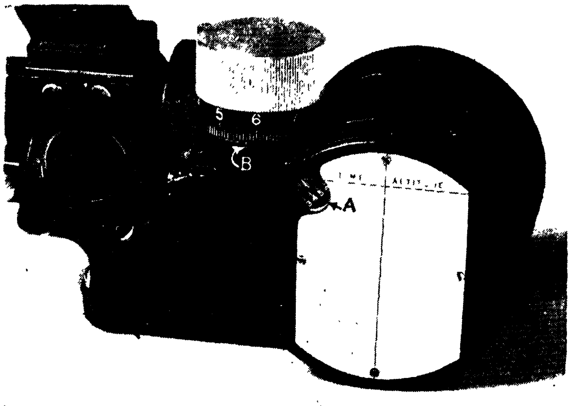


Fig. 297.—Reading an octant altitude (45°45′).

opposite *B*, Fig. 297. In this particular model the drum is divided into 10 degrees, and each degree is divided into twelve 5′ subdivisions.

Measuring Altitudes—Optional Position of Eyepiece.—The eyepiece of the Pioneer octant may be rotated 90° left or right of its normal position

A *B*

Fig. 298.—Optional method of observing altitudes to the left or right.

(see Fig. 298) so as to enable the navigator to observe altitudes to the left or right while facing straight ahead.

When the eyepiece has been rotated 90°, correct collimation occurs as shown at *A* and *B*, Fig. 299. Rotation of the altitude drum causes

the image to move from left to right as shown at *C*, not up and down as previously shown.

At any intermediate position of the eyepiece, such as a 45° offset position, correct collimation occurs as shown at *A* and *B*, Fig. 300.

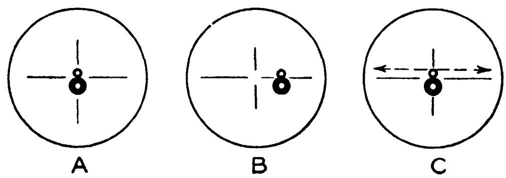


Fig. 299.—Correct collimation when eyepiece is turned 90° left or right.

This is important to remember because, if the eyepiece is pressed too firmly against the observer's eye, the eyepiece may be rotated inadvertently and incorrect collimation for that particular offset position may result. This is especially true in taking sights at night in a darkened cockpit or navigator's "blister."

Fig. 300.—Correct collimation with eyepiece offset 45°.

Use of the Astigmatizer.—The instrument is provided with an **astigmatizer,** which elongates the image of the celestial body and makes it appear as a short straight bar of light. When the astigmatizer is used, correct collimation is more readily achieved because it is somewhat easier to bisect the bubble with the elongated image than it is to estimate the

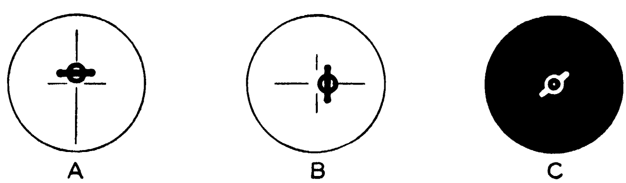


Fig. 301.—Correct collimation when using the astigmatizer.

mid-point of the bubble with a round image. In *A*, Fig. 301, the astigmatized image is shown properly collimated for normal eyepiece position. In *B*, collimation is shown as it occurs when the eyepiece is rotated 90° left or right. In *C*, collimation is shown at night at an intermediate position of the eyepiece.

In *A*, *B*, and *C*, Fig. 302, the dotted lines show the direction in which the astigmatized image moves when the altitude drum is rotated.

The astigmatizer, then, not only contributes to accuracy through enabling the navigator to bisect the bubble more accurately; it also contributes to accuracy since correct collimation is always assured when the bubble is bisected, regardless of the position of the eyepiece. For this reason, especially at night when the eyepiece may unknowingly be moved, the astigmatizer should be used.

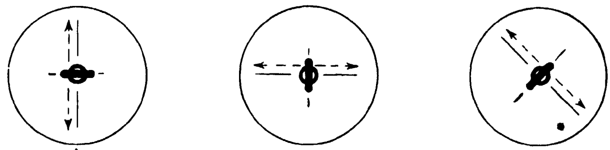


Fig. 302.—Movement of astigmatized image.

Choice of Bubble Size.—A large bubble, together with the image of the moon, is shown in Fig. 303. The moon appears to be located rather close to the horizontal bisector of the bubble; if it *is* located correctly, proper collimation is being achieved. Close inspection of the figure, however, shows that the moon is slightly above the horizontal bisector, and an erroneous observed altitude must result. That is, the bubble is too large to permit accurate bisection. The diameter of the moon as shown in this figure is approximately 30′ of arc and, when the lower edge of the moon is on the horizontal bisector line as shown, the measured altitude is 15′ in error. This, of course, will produce an error of 15 miles in the line of position—an error that, needless to say, could be very serious. While it is important to use an active bubble, this caution regarding unnecessarily large ones should be borne in mind.

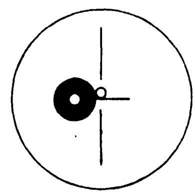


Fig. 303.—Bubble too large.

Accuracy of Observations.—In the air, under good conditions with respect to turbulence and visibility, successive altitudes taken with any bubble instrument may differ from each other by as much as 45′ of arc. For this reason, lines of position based on single observations are unreliable. In the author's opinion, an average of fewer than 5 altitudes will always prove unsatisfactory. When 10 altitudes are taken and averaged numerically, the following degrees of accuracy may be expected, provided that the student has had about 10 hr. practice with the instrument:

50 per cent accurate to within 5′.

82 per cent accurate to within 10′.

95 per cent accurate to within 15′.

Maximum error—18 to 23′ of arc.

It used to be customary to record the exact time in hours, minutes, and seconds at which each altitude in the series of 10 observations was observed. Ten observations were taken rather than 9 or 11 because it rendered the determination of the mean altitude somewhat easier, *i.e.*, the altitudes and times were added in separate columns, and the decimal point was moved over to obtain the mean time and mean altitude. An experienced navigator is able to obtain 10 altitudes of a body and record 10 observation times in a period of 2 to 2½ min. This means that individual altitudes are obtained about every 15 sec.

If the individual observations are taken with approximately even time spacing, much trouble, time, and mental effort can be saved by noting the first and last times of observation rather than the individual times. When these two times are added together and divided by 2, the resulting mean time of observation is generally close (to within 3 or 4 sec.) to the mean time that would have been obtained had each time been taken. If this procedure is followed, a series of 20 observations can be taken in about the same period required for 10 observations and 10 individual times. The mean time so obtained may be in error from 4 to 5 sec. and may introduce an error of 1 mile in the line of position, but this possible error is more than offset by the improvement in the resulting mean altitude. When 20 observations are taken, the following degree of accuracy in the mean altitude may be expected:

60 per cent accurate to within 3′.
85 per cent accurate to within 5′.
98 per cent accurate to within 10′.
Maximum error—11 or 12′ of arc.

This degree of accuracy does not represent the accuracy of an observer who has had considerable flight experience. Under normal conditions, the mean of 20 observations taken by an experienced navigator is accurate to within 5′ or less of arc.

In the beginning, it is recommended that the student navigator record 20 individual altitudes and the first and last times of observation. By putting the odd-numbered observations in one column and the even-numbered in another, he will record two sets of 10 observations and may apply the mean time of observation roughly to either group. He may then get some check on his proficiency by averaging each series of 10 and comparing the averages. At first, these averages may differ by as much as 20 or 30′ of arc. With practice, this difference may be reduced to about 5′ of arc.

It should be noted in passing that the accuracy of observations varies on different types of planes. Certain planes have a disturbing slow rolling characteristic, much as a large liner has at sea. This period of roll may coincide with the period between successive observations,

and the beginner may be unable to detect the slow oscillation of the octant bubble. As a consequence, all the observations may be taken when the bubble is being affected by a wing-up or wing-down acceleration. Other planes have a distinct tendency to "porpoise," and the same chance of error is present when observations are taken either directly ahead or astern. Error resulting from such accelerations may be avoided by taking as many altitudes as time allows without regard to the apparent stability of the plane at any position during the roll period.

The field of vision in an octant is rather small, and it is difficult to bring a star into this field by simply facing in its general direction and rotating the drum. Experienced navigators estimate the altitude of the celestial body, set the octant to this approximate altitude, and then search the sky by rotating the altitude drum. Ability to estimate altitudes should be acquired early; on a cloudy night when stars appear and disappear rapidly, it may make all the difference between getting a line of position and not getting it.

Checking the Zero Setting.—Prior to departure, the octant's zero setting should be checked by the navigator. It is assumed that the instrument will have been checked previously by the instrument shop; nevertheless, the navigator should reassure himself as much as possible that the instrument has not been damaged and rendered inaccurate in transit to the plane. It is impossible as a rule to check any setting except the zero setting, unless check instruments are available. The zero setting may be checked by forming the bubble and measuring the bubble altitude of the sea horizon. A series of 10 observations will ordinarily serve to reassure the navigator as to the accuracy of his instrument.

Time permitting, a more accurate check can be made as follows: The octant may be set on a stool on the apron, and the altitude of a marker on a similar stool some 1,000′ distant may be measured. This altitude, for example, might amount to 1°30′. The positions of the stools should be chalk marked and the marker and octant shifted to each other's former positions. The altitude should be measured from the reversed position; it may, for example, amount to $-1°$. The spread in the two altitudes in this instance amounts to $2\frac{1}{2}°$, and half this value represents the slope of the apron, *i.e.*, $1\frac{1}{4}°$. That is, the first octant altitude should have been 1°15′, and the second should have been $-1°15'$. Comparison of the $1\frac{1}{4}°$ slope to the altitude actually obtained shows that the octant reads 15′ high. In following this procedure the octant should be tapped *very lightly* with the finger in order to prevent the bubble's sticking in the field of vision.

Checking an Octant for Error during Flight.—It is most disconcerting to suspect the existence of an error in an octant while on flight. A series

of poor fixes, track, or speed lines may arouse just such a suspicion in the navigator's mind. The principle underlying the method of detecting an error may be briefly outlined as follows:

If lines of position are obtained simultaneously from two bodies directly opposite each other, the two lines should coincide. If the octant gives erroneously high readings, each line of position will be closer to its associated body than it should be. The separation between these two lines is thus equal to twice the error in the octant's reading. If the octant reads too low, the lines will also separate, but in this case the lines will be farther from their associated bodies than they should be. Again,

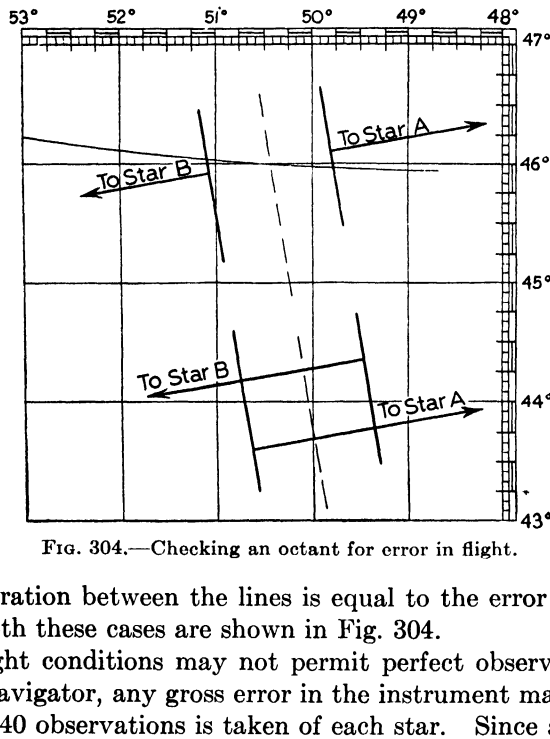


FIG. 304.—Checking an octant for error in flight.

half the separation between the lines is equal to the error in the octant reading. Both these cases are shown in Fig. 304.

While flight conditions may not permit perfect observations on the part of the navigator, any gross error in the instrument may be detected if a series of 40 observations is taken of each star. Since a few minutes are required to obtain such a series, it will be necessary to reconcile the two lines to a common time by advancing or retarding one of them. It should be pointed out that best results are obtained when stars of approximately the same altitude are chosen, since an octant error may not be uniform throughout the range of the scale.

Care of the Chronometer.—A typical aircraft chronometer is shown in Fig. 305. In construction, it resembles a high-grade watch rather than the conventional marine type chronometers. As a rule, an indicating device is provided on the face to show how long it has run since the last

winding. Like all timepieces, the chronometer may be expected to gain or lose a little each day. This daily **rate** may amount to a fraction of a second, or it may be as much as 5 sec.; if the rate is more than this, the chronometer should be cleaned and adjusted.

Since it is impractical to reset the chronometer every day in order to remove the accumulated error, a chronometer record is kept, indicating both the daily rate and the accumulated error. Allowance must be made for this error whenever use is made of the timepiece.

FIG. 305.—Typical aircraft chronometer.

It is considered good practice to wind the chronometer every 24 hr. even though it may be of a type that runs a full 7 days on one winding. This daily winding ensures using the same portion of the mainspring over and over again, which results in the maintenance of a more stable rate. Between flights, the chronometer is kept ashore under the observation of the navigation office; its daily rate and accumulated error are entered each day in the permanent chronometer record book.

While chronometers are temperature compensated and normally maintain a constant rate under minor temperature fluctuations, it is not to be expected that this rate will remain constant once the plane is in flight. At high altitudes, extremely cold temperatures are encountered;

and, unless the navigator's cabin is heated, this change of temperature may be expected to vary the daily rate somewhat.

Chronometers are usually mounted in a spring suspension or in sponge rubber to reduce shock due to take-off, vibration, and landing.

Checking the Chronometer.—If a series of observations is taken and timed according to a GCT that is in error 4 sec., the GHA taken from the Air Almanac will be 1′ of arc in error. This brings about an assumption of longitude that is 1′ in error, and the resulting line of position may be in error as much as 1 mile. Such an error may or may not be important, but proportionately greater errors in the line of position result from proportionately greater unknown chronometer errors. A chronometer error of 1 min. can bring about a 15-mile error in the line of position.

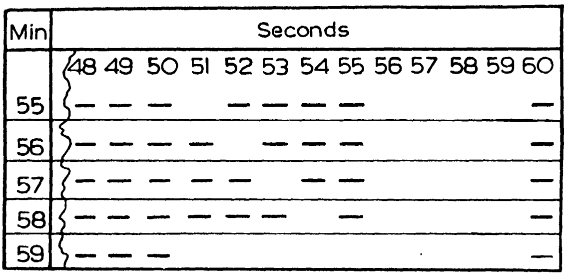


FIG. 306.—United States government time signal.

To provide a means of checking the accuracy of a chronometer during flight the principal nations of the world broadcast time signals. In the United States these signals are broadcast almost every hour and consist of a series of dashes as shown in Fig. 306. Transmission of signals begins 55^m-00^s after the hour and continues to the end of the hour. During this period a dash is transmitted every second except that there is no signal on the twenty-ninth second of any minute or on certain other seconds, as shown in the figure.

Notice that the number of dashes sounded in the group at the end of any minute indicates the number of minutes yet to be sent. In all cases the beginnings of dashes indicate the beginnings of the seconds, and the ends of the dashes are without significance.

Station WWV near Washington, D.C., transmits time signals on both 5,000 and 15,000 kc. continuously throughout the day and night. Exactly at the beginning of each 5 min. the steady tone of the signal is stopped. During a 1-min. pause the call letters WWV are transmitted three times.

Watches may be set either on the end of the tone at each 5 min. or at the *beginning* of the tone at 01, 06, 11, 16, etc. min. after each hour.

The beginning and end of the tone are accurate to a very small part of 1 sec.

The 5-min. periods cannot be separately identified. This requires that the chronometer error be known to within 2 min. If there is any doubt, one of the standard hourly time signals should be used to verify the time. In addition to the station tone, a series of ticks is transmitted each second. These ticks are not useful to the navigator except as an aid in identifying the station.

Use of Second-setting Watch.—The chronometer itself is not used directly for timing celestial observations. A second-setting watch such as that shown in Fig. 307 is used for this purpose. The watch is either attached directly to the octant or is worn as a wrist watch. The seconds dial of the second-setting watch can be rotated by means of the knurled nut *A* in order to make the second hand indicate correct seconds. In setting this watch to exact GCT, the seconds dial is first rotated until exact seconds are indicated (making allowance for any odd seconds error in the accumulated chronometer error), and the minute hand is then rotated by means of the stem in order to show exact minutes.

FIG. 307.—Longines second-setting watch.

Compass Compensation.—It was pointed out in a previous chapter (page 102) that magnetic fields in an aircraft cause the magnetic compass to point out directions other than correct magnetic directions. The difference between compass directions and magnetic directions was termed *deviation*, and the method of making allowance for it was discussed in detail.

It may be argued that, since some deviation—requiring arithmetical computation—is almost certain to be present on every heading, it makes little difference whether this deviation be large or small. The fact of the matter is, however, that in maneuvering in close quarters during instrument approaches there is little time to make allowance for deviation and under these circumstances a compass with large deviations becomes a menace to safe navigation.

There is also another very strong argument for reducing deviations by compensation. The presence of deviation indicates that the compass needle is being pulled to one side by a local disturbing magnetic force. Such a force increases the directive force of the needle on some headings

and decreases it on others, but a *net loss* of directive force results *for the compass as a whole.* Compasses are compensated, *i.e.*, the disturbing magnetic field around the compass is neutralized, not only to remove the deviation but also to equalize the directive force of the needle throughout the entire 360°. Compensation is achieved by installing or rearranging small permanent magnets contained in a small case directly above or below the compass.

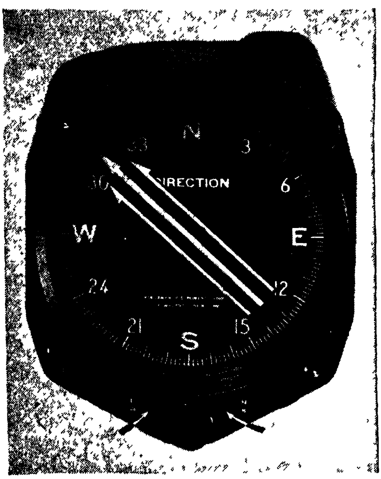


FIG. 308*A*.—Kollsman aircraft compass with compensating unit.

A compass with its compensating unit in place is shown in Fig. 308*A*. The compensating unit itself is shown in Fig. 308*B*; small permanent bar magnets are located at *C* and *D*. These can be varied in position with respect to each other by means of the north-south and east-west adjusting screws, and practically any desired correcting magnetic field can be created around the compass.

When a plane is heading magnetic north or magnetic south, all the deviation is produced by the disturbing force acting at right angles to the plane's axis. This force can be neutralized and the deviation removed

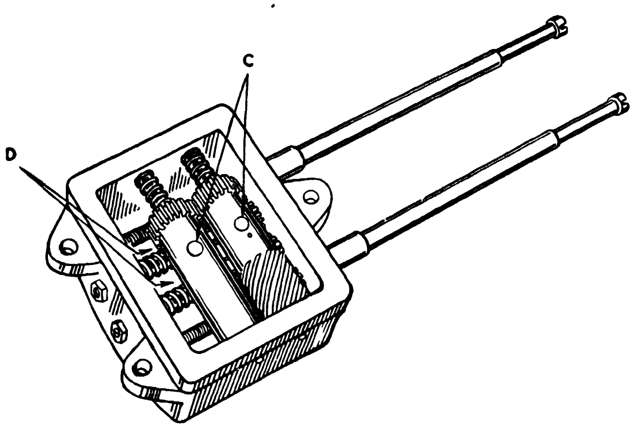


FIG. 308*B*.—Aircraft compass compensating unit.

by creating a neutralizing magnetic field through rotation of the north-south compensating screw. In heading magnetic east or west the disturbing force that acts in the fore-and-aft axis produces deviation.

This force can be neutralized and the deviation removed by rotating the east-west compensating screw.

Preparation for Compensation.—Compensation is usually performed on the ground in the center of a large compass rose that indicates correct magnetic directions. If such a rose is not already available, it may be constructed—well away from any steel buildings—by using a large magnetic compass and a long string or a surveyor's transit. If this equipment is not available, charts of the locality should be consulted to determine the true bearing of some prominent object from the center of the compass rose. Application of the local variation reduces this true

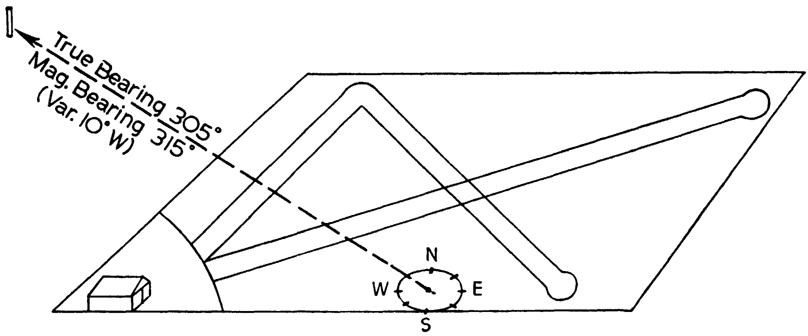


FIG. 309.—Use of charted bearing in constructing a compensating rose.

bearing to a magnetic bearing, which can be used to locate the major magnetic points on the rose. This method of constructing a rose is shown in Fig. 309.

The plane should be placed in the rose with the compasses at the center and then headed exactly magnetic north by means of plumb bobs suspended from the nose and tail. All movable equipment should be securely located in the position it will normally occupy during flight. The instrument-panel lights may be turned on, the radio may be turned on, or any other steps may be taken that will simulate—as much as possible—the flight conditions under which the compass will be used. On small ships, the tail may be blocked up in horizontal flight attitude, and it may be desirable to turn the motors over slowly.

Compass-compensation Procedure.—While the plane is heading magnetic north, the north-south compensating screw should be turned a little at a time until the compass reads north. The compass may be tapped lightly with the finger to prevent the needle's sticking, and after each adjustment of the compensating screw the compass should be allowed to settle down.

The plane should next be headed east or west, and the procedure should be repeated—this time, however, by rotating the east-west

compensating screw. Compensation on north and east not only removes the deviation on these two headings; it neutralizes practically the entire unwanted magnetic field around the compass, and little deviation should be found on any other heading.

Time permitting, the plane may now be headed south. If any deviation is noted on this heading, half of it may be removed by again rotating the north-south compensating screw. This procedure may be repeated on magnetic heading west (if the deviation was previously removed on magnetic heading east), and half of any deviation noted on this heading may be removed. This completes the compensation of the compass.

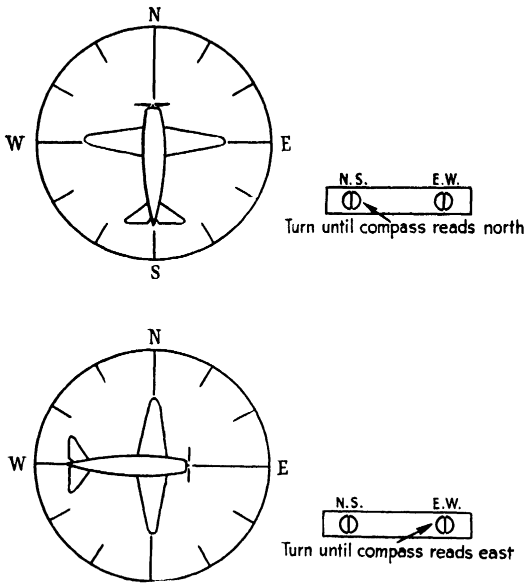


FIG. 310.—Compass-compensation procedure.

Compass Calibration.—The deviation on headings 20° apart should now be noted, and with this information a deviation graph such as that shown in Fig. 311 should be drawn up. The student's attention is again called to the fact that the compass has been compensated for a specific set of flight conditions and if these conditions are subsequently changed the deviations will not necessarily hold good.

Obtaining Deviations in the Air.—Because the deviation is apt to change under flight conditions other than those existing at the time of compensation, it is well to check the accuracy of the deviation graph en route as often as circumstances permit. This is usually done by calculating the true bearing of some heavenly body and comparing this calculated true bearing with the compass bearing of that body. The

difference between the true bearing and the compass bearing is, of course, the total error of the compass, part of which is made up of the variation for the locality. The balance of the total error is the deviation.

A time should be selected for the deviation check when the sun is not over 40° high; an altitude of 1 to 15° is to be preferred, since the compass bearing of the sun is more readily determined when its altitude is low. A **pelorus** such as that shown in Fig. 312 is mounted and checked for correct fore-and-aft alignment. The pelorus is used to measure the angle of the celestial body clockwise with respect to the nose of the aircraft, and this relative bearing when added to the compass *heading* of the aircraft supplies the compass *bearing* of the body.

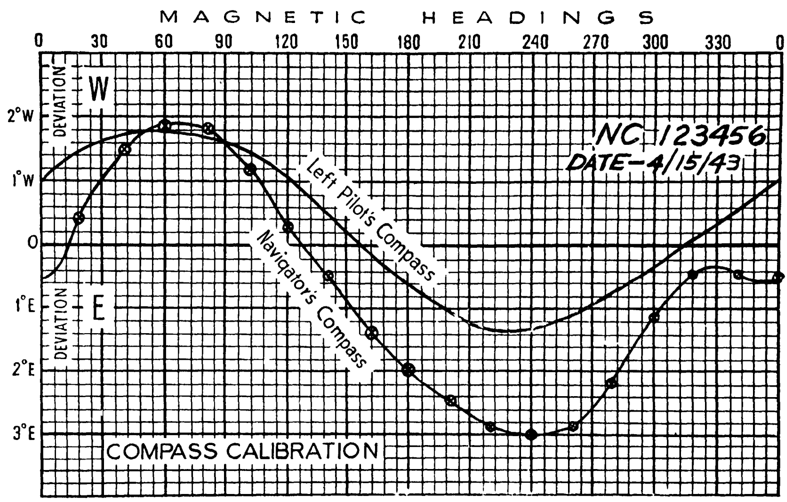


FIG. 311.—Compass-deviation graph.

Procedure.—When the compasses have become steady, the navigator gives a signal and for 2 min. thereafter both pilots record the readings of their compasses and the navigator records the relative bearing of the celestial body. During this interval perhaps 20 or 30 recorded readings may be made by each. It makes no difference whether one observer records more or fewer readings than the other; the purpose of the procedure is to obtain in each case the average reading of the compass and pelorus for the 2-min. interval. If the readings are taken at regular intervals, correct averages will be obtained and the *number* of individual readings is of minor importance.

The position of the plane and the GCT should be noted in order that, by means of the Air Almanac and either H.O. 214 or H.O. 208, the true bearing of the celestial body may be determined. All pertinent

data in connection with the deviation check are recorded on a permanent deviation record form such as that shown in Fig. 313.

If time permits, it is well to obtain the deviation not only on the compass heading but also on headings 20° either side. By so doing, a more accurate check on the deviation graph is obtained and the deviation of the compass is determined in advance for slight future changes of

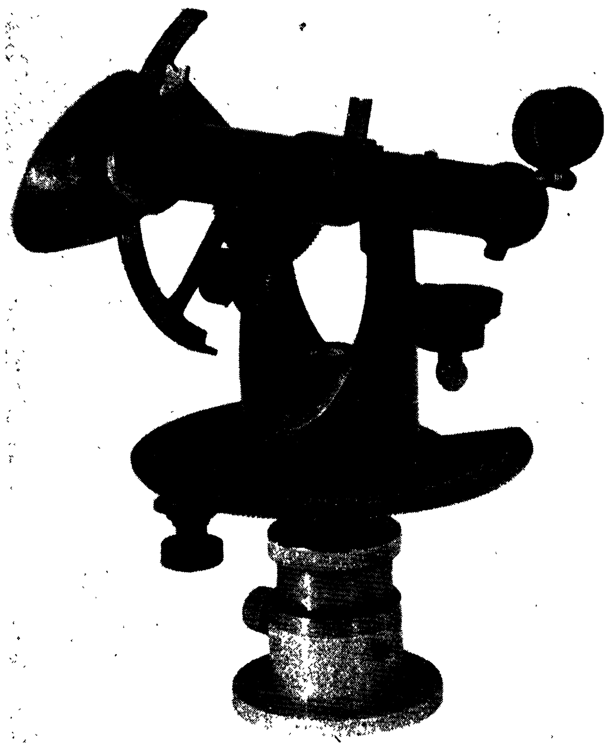


Fig. 312.—W. & L. E. Gurley pelorus.

heading. If the navigator can foresee other changes in heading, deviations should be obtained for these at the same time.

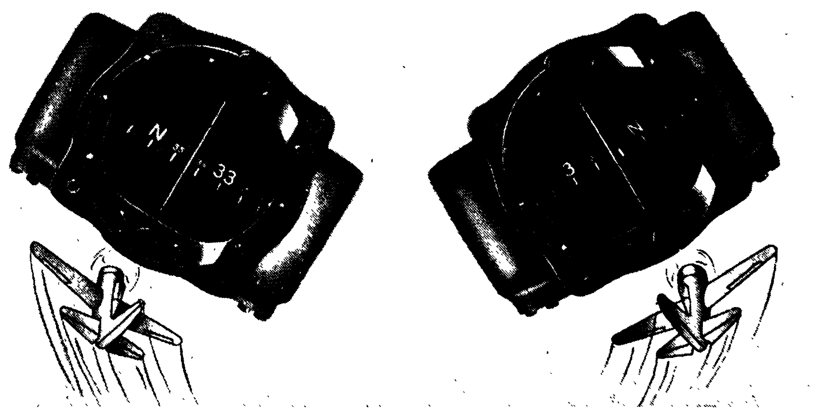
Northerly Turning Error.—There is no way to correct the so-called **northerly turning error,** since this is not caused by a disturbing magnetic field around the compass. This error, which results in erratic behavior or northerly headings, is brought about as follows: When a compass is turned on its side, the upright pivot becomes more or less horizontal and the compass card is free to rotate much like a wheel. In north latitudes there is a steady downward pull on the north end of the compass needle, although the effect of this force is noticed only when the compass is on its side and the north end of the needle is free to "dip."

In *A*, Fig. 314, the compass is shown tilted to the right as it would be just after commencing a right turn. In this position the effect of dip is such as to make the compass read less (350 to 340°) than north. In a rapid right turn the normal movement of the compass might be sufficient to overcome the dip movement, although in such a case the net result would be an indication of a rather slow right turn. In *B*, the compass is shown tilted to the left as it would be in a left turn from north, and in this position the dip effect causes a right turn to be indicated. Whether or not, during such a turn, the compass shows a right or a left change of heading depends on the relative strength of the two forces tending to turn the card.

COMPASS DEVIATION RECORD

Date	GCT.	Lat.	Long.	Comp. used	Average Compass Head.	Average Rel. Bearing	Comp. Bearing (Sum)	True Bearing	Total Err.	Var.	Dev.	Remarks
4-15 43	1310	40°N	72°20'W	Left pilot	163.4	313.0	116.4	106.4	10°W	12°W	2°E	PLANE STEADY

FIG. 313.—Compass-deviation record form.



A *B*

FIG. 314.—Northerly turning error.

Other Turning Errors.—In north latitudes the effect of dip on turns out of south is to accelerate the compass movement and show an exaggerated rate of turn. In south latitudes, northerly and southerly turning-error effects are reversed. From a navigator's standpoint these errors are important because they render the compass somewhat sluggish on northerly headings in north latitude—oscillations of 5 to 10° either side of north are not unusual. When deviations are obtained on these headings, it is necessary to record compass readings for a considerably longer period of time than normally required for east or west headings.

Radio Compass Calibration in the Air.—The purpose of this calibration is to determine and tabulate any errors found to exist in the loop-

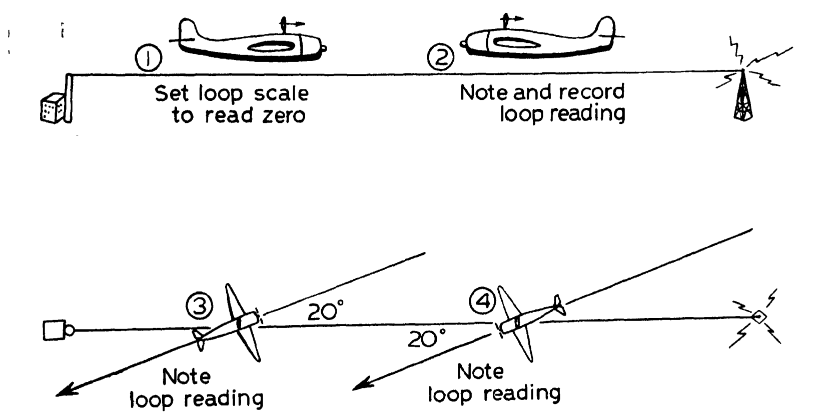


FIG. 315.—Calibrating a radio compass in the air.

antenna indications. The loop, for example, should read 180° in taking a bearing on a transmitter exactly astern. If it does not, the amount of the error must be determined and noted for future use.

Procedure.—Select a radio station for the calibration, and pick out a prominent building or smokestack about 5 miles away. Head the aircraft directly toward the transmitter, rotate the loop carefully, and establish the null point, *i.e.*, the position where no signal is heard. Loose the clamp on the azimuth wheel, rotate it until it reads 0 and reclamp it; this ensures that, when a bearing is taken straight ahead, the azimuth on the loop will read 0°.

Circle around, and cross the line of bearing between the transmitter and prominent marker at an angle of 20°. During the approach, establish the null point, and, at the exact time of crossing the line, note and record the loop reading. Continue this procedure at increasing angles until sufficient data are obtained to construct a deviation graph such as that shown in Fig. 316.

Air-speed Calibration.—The purpose of the air-speed calibration is to determine and tabulate erroneous air-speed indications. The true air speed of the plane is determined by flying over a measured route; this is compared with the air-speed indicator reading, and the difference is recorded. The procedure is repeated at various speeds from the very lowest to maximum.

Procedure.—The measured course should be about 5 miles long, and markers at right angles to the course should be established at each end.

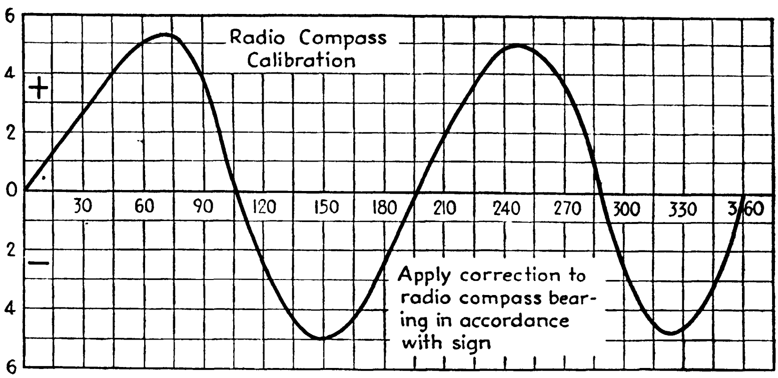


FIG. 316. Radio-compass-calibration graph.

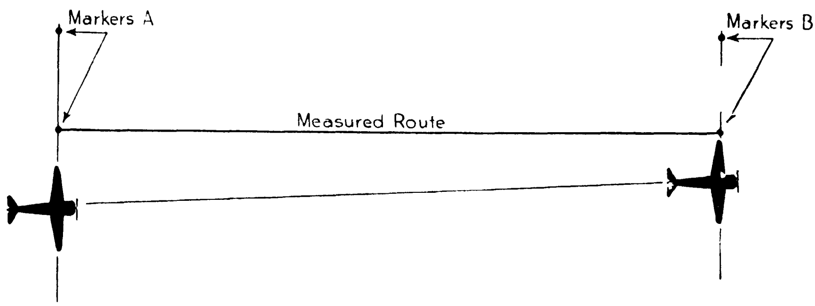


FIG. 317.—Air-speed-calibration procedure.

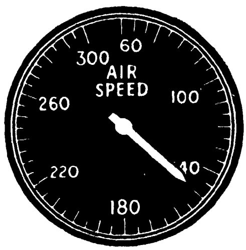
A day should be chosen for the work when the wind is very light or blowing at right angles to the measured course. Flight should be made at a low and constant altitude; and the air speed, which should have been steadied down during a 2-mile approach, should be held constant throughout the run. No allowance is made for wind; the heading is kept parallel to the measured course.

A stop watch is used to time the flight from a point in line with markers *A* in Fig. 317 until the plane reaches a point in line with markers *B*. Note the pressure altitude, temperature, and average indicated air speed.

The true air speed in knots is determined from the following equation:

$$\text{TAS} = \frac{\text{distance in nautical miles between markers} \times 3{,}600}{\text{average time in seconds}}$$

The average time used in this equation is the average time taken to fly from markers A to B and B to A. The calibration information may be either recorded graphically or tabulated as shown in Fig. 318.



IND	CAL
80	82
100	102
120	123
140	143
160	164
180	182
200	201
220	218
240	237
260	256
280	277
300	295

FIG. 318.—Air-speed-calibration chart.

CHAPTER XI

PRACTICAL SUGGESTIONS TO THE NAVIGATOR

Earlier in this volume the statement was made that the student navigator often finds himself unable to correlate and apply his acquired knowledge in flight. In part this may be due to faulty instruction; often, however, it is due to a lack of planning on the part of the navigator himself.

The following suggestions are given in the hope that they may help the student establish a tentative routine and encourage him to acquire the habit of planning ahead.

Preflight Routine.—Report to the airport an hour and a half before scheduled departure time so that you will not be forced to rush through your preflight work. During the first half hour, study the meteorologist's weather maps. Study the general weather conditions prevailing at the time, but also look back through the weather maps for the past few days so as to be able to evaluate weather trends in flight.

Board the plane with a check-out list of navigation equipment and charts, and make absolutely certain that all the equipment is in place and in good working order. Next, work out the flight-time analysis; and, having obtained the requisite fuel loads for various possible altitudes, submit the analysis and the weather forecast to the captain or commander for his consideration. Work up the flight plan for the chosen altitude, using the take-off fuel load supplied by the loading crew. This fuel load must be not less than the minimum specified for the trip; but if pay load is not available, it may be greater than the required minimum.

If your plane is a flying boat, prepare yourself in advance to conn (watch) the ship as it taxis to the take-off area. You will be expected to know depths of water and the buoyage system and to give information concerning these items to the commander as need arises. It would be embarrassing for you as a navigator if your flying boat were to run aground through lack of preparation on your part.

While the engines are being warmed up in preparation for the take-off, calculate the initial headings for both the left and the right pilots' compasses for the climb to flight altitude. Allowance must be made for the average wind anticipated in the climb. Usually, the numerical average of the local upper airs (supplied by the meteorologist) is used. Such a numerical average is certain to be in error at some altitudes, and it is

therefore necessary to keep an accurate account of the actual drift experienced during the climb. This drift may differ a few degrees from that indicated by the average wind, and the aircraft may not make the precise track desired. As a rule, the heading is not altered during the climb to make allowance for slight variations in wind; a check is kept on the plane's progress, and a new track is laid down from the leveled-off position.

Flight Routine.—Just prior to leveling off, determine and post new compass headings in the cockpit so as to get the plane headed in the general direction of the destination. These new headings are usually based on the forecast winds in the first zone.

After the plane has leveled off and picked up normal cruising speed, the drift must be checked again. The heading should be altered as required in order to stay on track; in the beginning of the flight, nothing is more important. There is very little that you can do to improve the ground speed; your duty is largely fulfilled when you have made sure that every mile of ground speed is being made good toward the destination. The immediate objective is always to improve the compass headings. As the flight progresses, the question of distance made good and the ground speed will become of increasing importance.

If you are unable to obtain drift owing to undercast weather conditions after leveling off, try to obtain a series of four to five radio bearings on a station directly astern. Individual radio bearings may be slightly in error; but if all the bearings show the plane to be off track, a line drawn from the starting point through the middle of the bearings may be used to indicate how much the plane has drifted off track, and any additional correction can be made.

If radio bearings cannot be obtained to establish the track, it may be possible to obtain celestial lines of position for this purpose. Since these are drawn at right angles to the bearing of the observed body, the navigator should make full use of bodies appearing to the right or left of the aircraft. Fixes may be determined if it is possible to do so; but if a choice must be made between obtaining a track line or a speed line, the importance of the track line in the early part of the flight must not be overlooked.

If the flight is long and you are the sole navigator, regulate your routine so as to avoid becoming unnecessarily fatigued at the end of the trip. In practice this means obtaining a three-star fix about every 2 hr. and a single line of position in between. Whether a track line or a speed line should be obtained between fixes will depend on which factor is most in doubt. In the event a track line is obtained, your position on it must be *estimated* by estimating the ground speed from the last fix. Before estimating your position on a *speed* line, throw a drift bomb

or water light overboard in order to get some check on your past drift assumption.

Think ahead. Do not wait until the last minute to arrive at a decision. You should be able to tell from your flight plan or "howgozit" whether or not the plane's progress is satisfactory. About an hour before reaching the point of no return make absolutely certain that a speed line or preferably a three-star fix is established. It is on the basis of this speed indication and your assumption of future weather conditions that the decision to continue is made. It is your duty to watch weather conditions; if it becomes apparent that celestial bodies will soon disappear, an immediate effort to establish a fix must be made.

Sunrise—Sunset—Moonrise—Moonset.—During a night flight you will be interested in knowing the time of moonrise and sunrise and during a daylight flight the time of moonrise and sunset. Knowledge of the GCT of sunrise and sunset will indicate when you should endeavor to obtain star fixes; knowledge of moonrise may avoid an unnecessary climb at night to obtain star observations and during the day may enable you to obtain a sun-moon fix.

Before the GCT of these events can be calculated for a plane in flight, a preliminary calculation of the time of occurrence at a fixed point becomes necessary. The GCT of such events at various latitudes on the Greenwich meridian is tabulated on the daily American Air Almanac sheet, as shown in Fig. 319.

According to this tabulation, sunrise on the Greenwich meridian at 50°N. Lat. occurs at 0510 GCT. Moonrise occurs at this point at 1322 GCT, sunset at 1852 GCT, and moonset at 0316 GCT.

The GCT of such an event at a west longitude position is always later than at Greenwich; conversely, a GCT earlier than that for the Greenwich meridian applies for east longitude positions.

Consequently, the GCT of sunrise or sunset at any meridian other than Greenwich is obtained by applying a time interval corresponding to the longitude difference. One degree of longitude is equivalent to 4 min. of time. Thus, if the time of sunrise at 90°W. Long., 50°N. Lat. is required for Apr. 15, 1943, it may be found as follows:

GCT of Greenwich sunrise (50°N. Lat.), Apr. 15	05^h10^m
Corr. for 90°W. Long. (90 × 4)	06 00
GCT of sunrise at 90°W. 50°N., Apr. 15	11^h10^m

At 90°E. Long. 50°N. Lat. the GCT of sunrise occurred 6 hr. earlier than at Greenwich.

This same procedure could be followed for the moon were it not for the fact that the moon rises 20 min. to over 1 hr. later each day. Hence, not only a correction for longitude becomes necessary but a correction

for lag as well. The lag for a 24-hr. period is tabulated in the Diff. column beside the GCT of moonrise-moonset at Greenwich (see Fig. 319). When the moon has moved 90° west after rising at Greenwich, a quarter of this correction must be applied. Thus, at 90°W. Long.

Lat.	Sunrise	Twil.	Moonrise	Diff.
N °	h m	m	h m	m
60	4 47	48	12 50	74
58	52	45	12 58	72
56	4 57	41	13 05	69
54	5 02	39	11	68
52	06	37	17	65
50	10	35	22	64
45	17	31	32	62
40	24	29	41	59
35	30	27	49	56
30	34	25	13 56	54
20	43	23	14 07	51
10	50	22	18	48
0	5 57	21	27	45
10	6 04	22	36	43
20	11	22	46	40
30	18	24	14 58	37
35	23	26	15 05	34
40	27	27	12	33
45	33	29	21	30
50	40	32	31	27
52	43	33	36	26
54	46	35	41	25
56	50	37	47	23
58	54	39	15 54	20
60 S	6 59	42	16 01	18

Lat.	Sunset	Twil.	Moonset	Diff.
N °	h m	m	h m	m
60	19 15	47	3 49	20
58	09	43	41	21
56	04	40	33	24
54	19 00	38	27	25
52	18 56	36	21	27
50	52	34	16	28
45	44	30	3 04	31
40	37	29	2 54	34
35	32	27	46	35
30	26	25	38	38
20	18	23	25	41
10	10	22	14	43
0	18 04	21	2 03	46
10	17 57	22	1 53	48
20	50	23	41	51
30	42	24	28	54
35	38	26	20	56
40	33	28	12	58
45	27	30	1 02	60
50	20	32	0 49	63
52	17	34	44	64
54	13	36	37	66
56	10	37	30	68
58	05	39	22	70
60 S	17 01	42	0 13	72

FIG. 319.—GCT of sunrise, sunset, moonrise, and moonset.

50°N. Lat. the moon rose, Apr. 15, 1943, at 1938 GCT. This value was obtained as follows:

GCT of Greenwich moonrise (50°N. Lat.)	13^h22^m
Corr. for 90°W. Long. (90 × 4)	06 00
Corr. for lag (¼ of 64)	00 16
GCT of moonrise at 90°W. 50°N., Apr. 15	19^h38^m

In 90°E. Long. 50°N. Lat. the GCT of moonrise would have been 6^h-16^m earlier than the GCT of Greenwich moonrise.

In Fig. 320 the miles vs. time portion of a typical "howgozit" sheet is shown. Point X indicates the time of sunrise at the point of departure, and point Y indicates the time of sunrise at the destination. These values of GCT were obtained as described above. The line XY shows the GCT of sunrise at any distance from the point of departure. Sunrise at the plane will occur where the miles vs. time line crosses line XY—

if the plane is on schedule. If the plane is off schedule, sunrise in flight will occur where the dotted line of actual miles vs. time crosses *XY*. The graphic solution for sunset, moonrise, and moonset is precisely the same.

Choice of Bodies for a Two-star Fix.—Best two-star fixes result from observations of two bodies whose true bearings differ 90°; application of

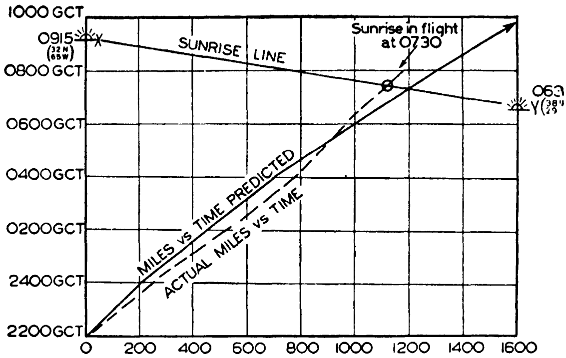


Fig. 320.—Determining the GCT of sunrise on the "howgozit" graph.

tolerances to such lines results in a relatively small area of possible positions. It makes little difference to an experienced observer whether one body bears ahead and the other abeam or whether the bodies are observed at other angles with respect to the heading. A good fix results in either case as shown in *A* and *B*, Fig. 321.

The inexperienced navigator may obtain slightly better results from observations of bodies that bear 45° either side of the heading. When such bodies are observed, the acceleration of the bubble horizon due to rolling or "porpoising" is somewhat less extreme.

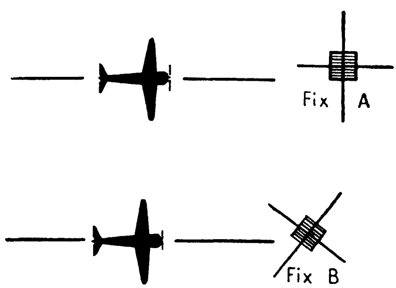


Fig. 321.—Two-star fixes.

Choice of Bodies for a Three-star Fix.—Best three-star fixes result from observations of three stars whose azimuths differ 60° from one another. There is a very definite procedure to be followed in obtaining such a fix. The first step is to select two prominent bodies separated by as near 120° in azimuth as possible. A search is then made for a third body midway between these two (or 180° opposite). Frequently, this third body will be a second-magnitude star that would not otherwise have been chosen for the fix. Too often, navigators attempt to obtain three-star fixes by observing the three brightest stars in the heavens without prior consideration of their azimuths. Satisfactory results in

such instances are rare and accidental. It is recommended that observations be taken on bodies whose altitudes do not exceed 60°. Lines of position so obtained are not more accurate in themselves, but the azimuth spread between bodies is more easily estimated when they are low.

Miscellaneous Duties in Flight.—The navigator's problem would be much simplified if he were charged solely with obtaining fixes and drifts and setting up new compass headings. Actually, he must discharge a host of duties, and one of his problems is to allocate his available time so as to perform these extracurricular functions without losing track of the plane's position.

At some time during the flight the navigator will most certainly wish to obtain the deviation of his compasses. This may require 10 to 25 min. work on his part, and such work is bound to upset temporarily his established routine. He may also be called upon to decode weather reports, draw weather maps, and analyze weather conditions. These, while pertinent to the general problem of navigation, cannot fail to upset his navigational schedule unless he has acquired the ability to intersperse such activities with his purely navigational duties. In addition, there is also the ever-present task of keeping the logbook up to date. Every hour the position, wind, weather, heading, fuel reserve, temperature, and altitude must be entered in the logbook. The mere entry of these figures takes only a few minutes, but the determination of the values occasionally requires much time.

The navigator, then, while keeping in mind the main navigational problem, must at the same time keep his routine flexible enough to allow him to perform the associated duties just mentioned.

Preparation for Approach.—After the estimated time of arrival (ETA) has been sent in to the destination, the navigator must concern himself with the problem of the approach. To a certain extent each approach presents its own distinct problem. For a night approach, the government light lists for the vicinity should be studied in advance to refamiliarize the navigator with the lighthouse characteristics, colors, and locations. Nothing is more disconcerting than to make a coast line in the middle of the night and be unable to tell one light from another. If the approach is made during the early morning hours, it is not unusual to mistake cloud banks for the coast line or the island of destination. *Do not neglect the purely navigational aspect of the approach.* Keep laying down lines of position on the chart until you yourself are satisfied that the destination is really sighted. Do not rely entirely on radio bearings. These have been known to disappear or become erratic when most needed.

Approach—Running Down a Line of Position.—If the destination lies on a coast line, it may be well to make a positive error to one side

or the other in order that there may be no doubt as to which way to turn when land is finally sighted. In approaching an island the following method may be utilized, provided that the sky is clear:

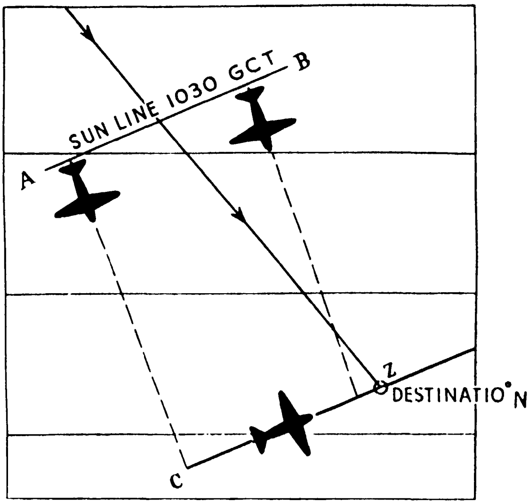


FIG. 322.—Running down a line of position.

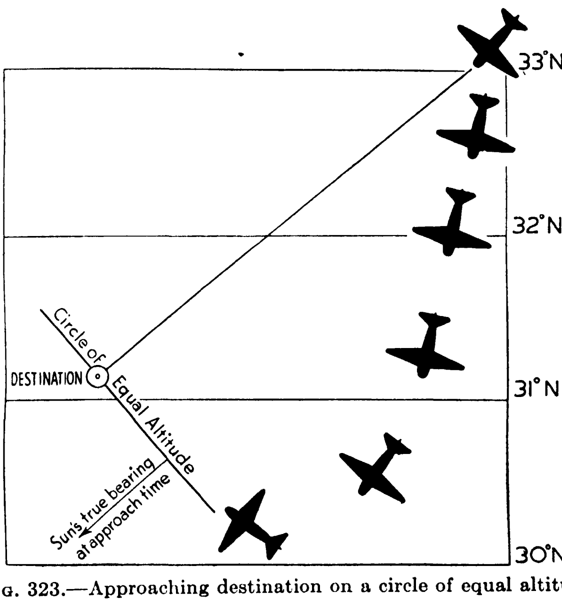


FIG. 323.—Approaching destination on a circle of equal altitude.

Establish a line of position such as AB, Fig. 322; the plane must be somewhere on this line. Redraw this line through the destination. While the plane's position on AB must be considered indeterminate, a

track may be followed that, regardless of the plane's position on AB, will take the plane to a given side of the destination. Such a track is shown in the figure. After having made good the intervening distance,

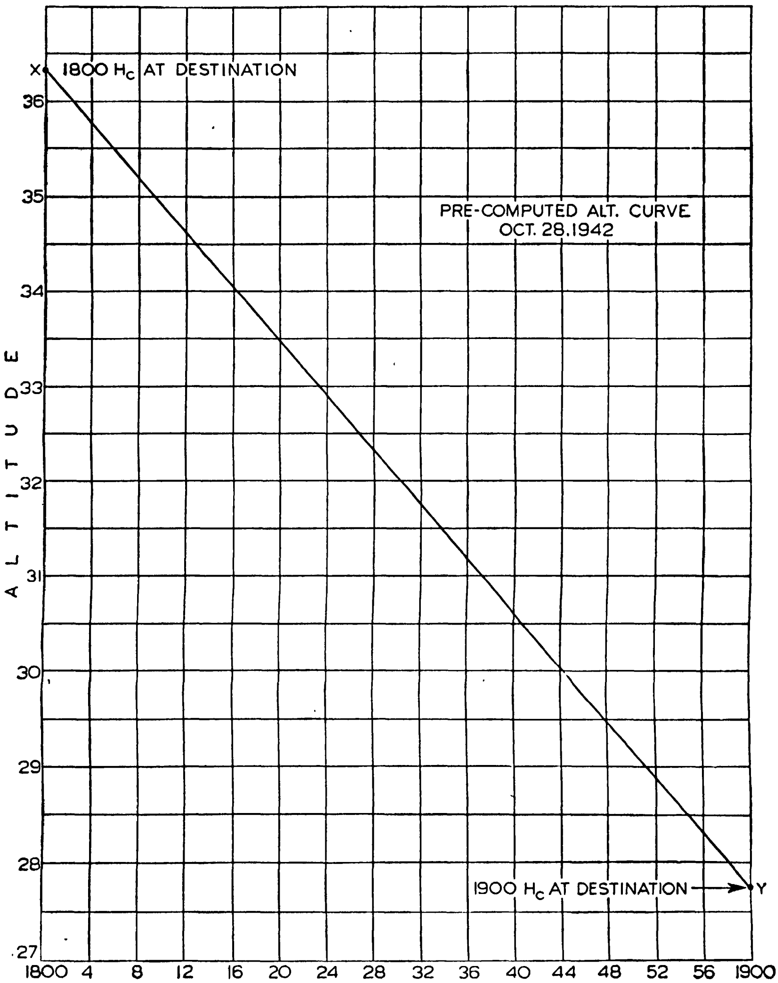


FIG. 324.—Graphing the precomputed-approach altitudes.

the heading is changed so as to proceed straight down the redrawn line of position to the destination. The success of such an approach depends on accurate dead reckoning.

Approach by Means of Precomputed Altitudes.—Weather permitting, an exact approach may be made by means of a precomputed altitude curve. In making such an approach the objective is to get the plane onto a circle of equal altitude that passes through the destination and

to keep the plane on this circle until the destination is sighted. This means that, after the plane reaches the circle of equal altitude, subsequent observed altitudes at the plane and at the destination must be kept equal (see Fig. 323).

A celestial body having been chosen for the purpose, its altitude at the destination is calculated for a GCT 30 min. before and 30 min. after scheduled arrival. With these altitudes and times a graph such as that in Fig. 324 is constructed. Line *XY* contains all possible altitudes of the celestial body at the destination for the entire approach interval.

With this graph at hand, the plane is headed to one side of the destination, and the navigator commences checking his observed altitudes

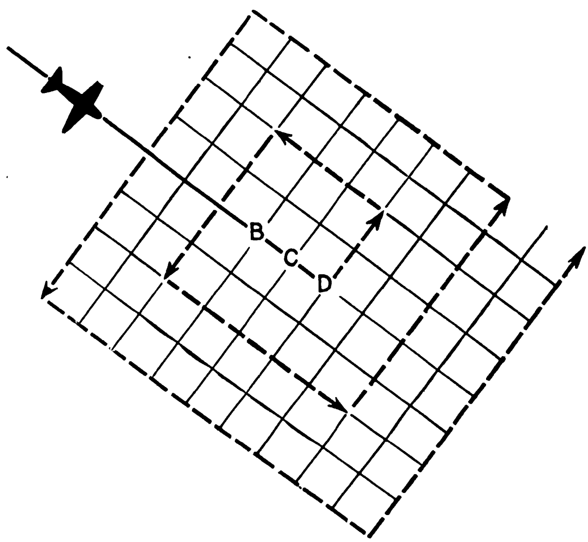


Fig. 325.—Square search.

against those plotted on the graph for the time of observation. When the observed altitude agrees with that shown on the graph, the plane has reached the circle of equal altitude that passes through the destination.

The next step is simple. The plane is turned toward the destination until the celestial body is at right angles to the heading. Altitude observations are continued in order to detect any drift from the circle of equal altitude. Should the observed altitude become less than the plotted altitude, the plane has drifted a little outside the circle; if the observed altitude becomes greater than that plotted, the plane has moved inside the circle. Small changes of heading will usually suffice to edge the plane back to where observed and plotted altitude again agree.

Square Search.—In the event the destination cannot be found, a systematic search should be instituted at once. Such search procedures

should be as simple as possible from a navigational standpoint in order to facilitate determination of proper compass headings.

The square search is shown in Fig. 325. The plane arrived at *B*, where the navigator expected to find his objective and having failed to find it elected to make a square search. In order to avoid searching too much of an area at a time, the visibility was estimated by dropping a smoke bomb. *BC*, Fig. 325, is equal to nine-tenths of this estimated visibility. From *B* the plane held to its original track to point *D*, twice the distance *BC* from *B*. A track 90° to the left was then made for a distance equal to twice *BC*, and thereafter tracks 90° to the left were made at the end of the distances 3*BC*, 4*BC*, 5*BC*, 6*BC*, etc., until the destination was located.

While the visibility in nautical miles can be calculated from the equation

$$\text{Visibility} = 1.15 \sqrt{\text{altitude in feet}}$$

this method is not recommended because such a theoretical visibility can be greatly reduced by haze conditions.

Summary.—In this volume the basic problems of the navigator on the ground, during flight, and during the approach have been discussed in detail. Proficiency in solving these problems can be acquired through drill. The mark of the experienced navigator is his ability to solve them rapidly, evaluate past performance, and estimate future performance.

Navigation calls for a high degree of coordination, painstaking attention to details, and sober judgment under trying conditions. The best advice that can be given the beginner in this profession is to *think ahead.* The speed with which planes travel makes this imperative if safety is to be ensured.

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